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VESTIGIAL INSTINCTS IN INSECTS AND OTHER ANIMALS[1]

By WILLIAM MORTON WHEELER

The once widely accepted notion of instinct activities as fixed and immutable processes of inscrutable origin has been definitively discarded and replaced by the view that they, like the organism of which they are an expression, are capable of a considerable degree of individual fluctuation or variability. As James[2] says: "In the instincts of mammals, and even of lower creatures, the uniformity and infallibility, which a generation ago were considered as essential characters, do not exist. The minute study of recent years has found continuity, transition, variation and mistake, wherever it has looked for them, and decided that what is called an instinct is usually only a tendency to act in a way of which the *average* is pretty constant, but which need not be mathematically true." Similar statements have been made by other authors imbued with the importance of the genetic study of animal behavior. H. E. Ziegler says:[3] "All the principles that have been established for the morphological consideration of organs hold good also for the instincts; when we refer to them, we also speak of homology, analogy and parallel development, of individual variation, of natural selection and its purposeful result, of artificial selection and hybridization, of becoming vestigial, of re-

[1] Read before the section of Psychology and Anthropology of the New York Academy of Sciences, Nov. 25, 1907.

[2] The Principles of Psychology, II, New York, Henry Holt, 1890, p. 391, *nota*.

[3] Ueber den Begriff des Instincts. Verhandl. deutsch. zool. Gesell. Leipzig, 1891, p. 134 *et seq.*

version (atavism); both here and there we recognize instances of inhibition of development, of natural and artificial abnormalities." As a rule, however, writers have been most concerned with the development or evolution of instinct activities, and have said little or nothing about their involution or disappearance. Permit me for the present to leave the deadlock of opinion on the origin of instincts, as I have no means of deciding whether these are inherited, mechanized, individually acquired activities as claimed by the Neolamarckians, or spontaneous, congenital mutations as claimed by the Neodarwinians, and let us consider some of the cases of their gradual waning and evanescence.

Darwin seems to have been the first clearly to recognize certain animal instincts as purposeless relicts of once highly purposeful adaptations. He dwells on these cases in connection with the expression of the emotions in man and the effects of domestication on animals. G. H. Schneider summarizes Darwin's observations in connection with his own remarks on vanishing instincts, as follows:[1] "Just as the tenacity of heredity accounts for the transmission of organs which have been functionless and vestigial for generations, so it also transmits vestigial impulses (Triebe), or relations between cognitive acts and impulses, which are now purposeless. I allude especially to the oft-cited case of the dog, which, just before lying down, often turns for some time in a circle, even when it is in a room, and not, like its feral ancestors, in the wilds where this gyration is executed for the purpose of treading down the grass. I would further call to mind certain well-known motions of house-dogs and house-cats, which like their feral allies, try to cover their excrement, even in places where there is no sand. These particulars have been far too little observed in animals, or we should undoubtedly be able to cite many other similar examples. Man, too, is known to have such vestigial impulses. The most familiar of them are what I have called the movements of intimidation. Although in civilized man the instinctive uncovering of the canine tooth in the expresssion of contempt, or of all the teeth in rage, has no longer the purpose of intimidating the enemy by a display of weapons, this habit has nevertheless been retained down to the present time. Similarly the aspirated interjection often uttered in a fit of rage, and so like the 'spitting' of the carnivores, is now purposeless, though the impulse to this form of expression is still generally inherited."

The examples of vestigial instincts cited by Darwin and Schneider all agree in conforming to the definition of instinct

[1] Der Thierische Wille: Leipzig, Ambr. Abel, 1880, p. 418, 419.

as an action performed by all the individuals of a species in a similar manner under like conditions. There is, however, another category of these vestiges which seems to represent a more advanced stage of decay or evanescence, in that they seem to be performed only by certain individuals of the species, in circumscribed portions of its geographical range, and only under very unusual stimuli. In my study of the ants, I have repeatedly come upon instinct vestiges of this character, remains of activities that must once have been of the greatest importance to the species, but have since fallen into desuetude and been overlaid or all but completely replaced by more recently acquired instincts. Cases of this description are most obvious in the parasitic species or in those that have changed their nesting habits within comparatively recent times. Forel has called attention to vestigial slave-making instincts in *Strongylognathus huberi* and *rehbinderi*,[1] ants now living as abject parasites in the nests of *Tetramorium cæspitum*, but in all probability descended from slave-makers like *Polyergus rufescens*, which they still resemble in the peculiar falcate structure of their jaws. *P. rufescens*, too, has its vestigial instincts. The workers of this species are no longer able to take food except from the tongues of their slaves, and perish when these attendants are removed, but the queens have retained to a very slight degree the ability to feed independently. This case, and many others that might be cited, are interesting as proving that the castes in polymorphic insects may show different stages in the decay of the same instinct, a condition obviously correlated with visible differences in physical organization and dependent in ultimate analysis on the physiological division of labor so beautifully developed in these and all other social insects. In other words, we not only find the ants exhibiting vestigial instincts as species, but a certain caste within the species may show vestiges of instincts whose full exercise is the normal prerogative of a different caste. Thus under extraordinary circumstances, the usually sterile worker may lay eggs, like the female, or the female may occasionally forage like the workers or accompany them on their slave-making expeditions. In *Leptothorax emersoni*, an ant that lives with *Myrmica canadensis*, I have observed an even more striking example of an obsolescent feeding instinct. The *Leptothorax* when living with the *Myrmica*—and in a state of nature it is never found except in this association—always obtains its food either from the tongues of its hosts (*i. e.*, by regurgitation), or by licking their oily bodies, but when it is

[1] Strongylognathus Huberi et voisins. Bull. Soc. Ent. Suisse X, 7, 1900, pp. 273-280; Miscellanea Myrmécologiques, Rev. Suisse Zool. XII, 1904, p. 2.

separated from the *Myrmica* in an artificial nest it begins to visit the food dish and feeds, rather awkwardly at first, but eventually quite like the non-parasitic species. In this case an instinct, which would certainly be put down by the casual observer as completely absent, can be resuscitated under the conditions of an artificial experiment.[1]

The nidification of ants and other social insects furnishes several examples of vestigial activities, one of which I have described in detail in a former article.[2] *Cremastogaster lineolata*, a common North American ant, which nests in the ground or in rotting wood, belongs to a largely tropical, arboreal genus, many species of which construct great paper or carton nests, roughly resembling the nests of certain social wasps. On very rare occasions, and in a few localities, however, *C. lineolata*, constructs small carton nests or diminutive "sheds" of the same material over the plant-lice and mealy-bugs on whose saccharine excrement it feeds. This is obviously a feeble reminiscence of formerly well-developed carton-building instincts.

I will cite three other cases of vestigial instincts of nidification. The common honey bee (*Apis mellifera*), which in a state of domestication prefers to suspend its waxen combs in closed hives, readily becomes feral and then nearly always takes up its abode in hollow tree trunks. On very rare occasions, however, it suspends its combs in exposed situations from the branches of trees. The form and position of these combs are so much like those of certain species of *Apis* (*A. dorsata* and *florea*) in southern Asia, where the honey bee lived before it was domesticated and exported to temperate regions, that we are justified in interpreting this very unusual method of nidification as a return to ancestral conditions; in other words, as a revival of a lingering or vestigial instinct, called forth by some unusual stimulus, such as the inability to find a suitable nesting cavity at the proper time and in the proper place. The manifestation of this instinct in temperate regions is worse than purposeless, for it leads to the extinction of the colony on the approach of winter.

This case of the honey bee leads me to the consideration of another comb-building insect, one of our common wasps (*Polistes metrica*), which is also of tropical origin. It has, how-

[1] For an account of the symbiosis of these ants see my papers: The Compound and Mixed Nests of American Ants. Amer. Natur. XXXV, 1901, pp. 431-448; Ethological Observations on an American Ant (Leptothorax Emersoni Wheeler), Arch. f. Psychol. u. Neurol. II, 1903, pp. 1-31, 1 Fig: and Notes on a New Guest-Ant, Leptothorax glacialis, and the Varieties of Myrmica brevinodis Emery. Bull. Wis. Nat. Hist. Soc. V, 1907. pp. 70-83.

[2] The Habits of the Tent-building Ant (Cremastogaster lineolata Say). Bull. Am. Mus. Nat. Hist. XXII, 1906, pp. 1-18. pll. I-VI.

ever, migrated of its own accord into northern regions and has acquired a new series of instincts in adaptation to the great changes of the seasons and the food supply. This insect builds small paper combs and feeds its larvæ on the nectar of flowers and fragments of insects. It does not, as a rule, store up these substances, but uses all the cells of its comb for breeding purposes. In the autumn the colony perishes, with the exception of one or a few fertilized females, which hibernate under the bark of trees, in barns or in the attics of houses and start fresh nests and broods during the ensuing spring. The following observations show that *P. metrica* and some other species of the same genus may exhibit vestiges of instincts once highly developed in their ancestral tropical environment.

November 3, while walking with Professor J. M. Cattell over his estate at Garrison-on-Hudson, I found a number of small nests of *Polistes metrica* hanging from the eaves of a boat-house. These nests were empty and abandoned by the insects, with the exception of one, about 5 cm. in diameter and consisting of a few dozen cells. Four female *Polistes*, inactive with the cold, were clinging to the comb, six of the cells of which contained half grown, much contracted, but still living larvæ. There were small drops of a colorless liquid in many of the other cells and one of them was half full of this substance, which was tasted and proved to be honey of an agreeable flavor. The drops hung suspended in the angles of the cells, but were without any definite arrangement and varied much in size. This honey must have been collected some weeks previously from the autumn flowers and stored, now that nectar and insect food were no longer to be had, for the purpose of bringing the few remaining larvæ to maturity. This belated brood undoubtedly accounted for the presence of the female insects at so advanced a date.

I doubt not that other entomologists have noticed this tendency of our species of *Polistes* to store honey, but the habit is certainly very infrequent. Among the observers who have studied European species of *Polistes* most closely, von Siebold and Ed. André have made no mention of this peculiar instinct. It has, however, been noticed by Lepeletier,[1] Rouget[2] and Marchal.[3] Lepeletier says concerning *Polistes gallica* that "at the time when the comb, in process of construction, contains cells suitable for the education of the males and fertile females, the worker *Polistes* begin to collect the provisions of honey that seem to be necessary for the preparation of the food which is to

[1] Histoire Naturelle des Insects Hyménoptères, I, 1836, p. 496.
[2] Sur les Coleoptères Parasites des Vespides, Dijon, 1837, p. 37.
[3] Observations sur les Polistes. Bull. Soc. Zool. France, XXI, 1896, pp. 15-21, 2 figg.

develop the reproductive powers of these individuals." Rouget, who kept *Polistes* colonies in captivity, found that in the beginning of October, when most of the cells were empty, the insects filled them with a kind of honey, which resembled in color the unrefined sugar with which they had been fed. More explicit observations have been published by Marchal from whose paper the above references are taken. He describes as follows several nests of *P. gallica* var. *diadema* sent him from Lot-et-Garonne, France: "Fifteen nests were sent by my correspondent, the smallest exhibiting 6, the largest 59 cells; all containing as yet only eggs or very young larvæ. Six of them had 5 to 8 cells containing honey. These were situated in the portion of the comb furthest from the pedicel, and the honey was placed on the wall nearest the periphery, about half way between the bottom and the free border of the cell, in the form of a large, colorless drop, adhering to the alveolar wall, and of syrupy consistency and beautiful transparency.

"Microscopic examination revealed in it the existence of a few pollen grains, various foreign bodies, such as certain curved, refractive filaments whose nature could not be determined, spores of rust, the scales of a Lepidopteron, etc., but these bodies were present in small quantity and did not interfere with the transparency of the honey. Its flavor was saccharine and very agreeable. For the most part, the nests containing the honey had reached a stage with more than 30 cells (the smallest had 25, the largest 59); all the nests without honey had 30 cells or less.

"The honey, although generally occurring in cells already furnished with an egg, must evidently represent a provision; for it was precisely the oldest cells, and those nearest the pedicel, containing recently hatched larvæ or eggs ready to hatch, that were destitute of honey. This honey is not, therefore, for the nourishment of the larvæ in the cells in which it is placed, but is simply stored up to be again removed and distributed among the larval colony. I found honey in some cells that contained no eggs or in which the egg had been destroyed or had shriveled to a mere pellicle. This fact seems to point to a beginning specialization on the part of the queen *Polistes* in establishing cells for provisions, but most often, as has been stated, the egg remained intact above the provisions.

"It follows from the preceding observations that *Polistes* is able to collect honey *from the very beginning of founding its nest*, when the queen alone exists. This fact therefore completely precludes the supposition [of Lepeletier] according to which honey is collected by the wasps for the production of the fertile females. All the larvæ of the nest receive nourish-

ment made of the same elements and of a mixed character, that is, both animal and vegetable."

The storing of honey by *P. americanus* in Lower California was recorded several years ago by Brongniart.[1] He says that the nest of this species "always contains larvæ and nymphs, but only during the winter are the cells of the median portion of the comb filled with pale yellow, transparent honey." Some of this honey was sent to the chemist Bertrand, who analyzed it with interesting results.[2] It is known that in general the sweet substance collected by honey bees is composed of almost pure saccharose. This sugar is split up in the proventriculus of the insect into a mixture of dextrose and levulose. It is this mixture, sometimes called invert sugar, accompanied by a small residue of unaltered saccharose, that constitutes ordinary honey. It turns the plane of polarized light to the left. The honey of *Polistes*, on the contrary, turns it to the right, and seems to consist exclusively of dextrose and saccharose without levulose." Bertrand infers from this fact that *Polistes* either does not, like the bees, alter the constitution of the nectar which it collects, or obtains its honey from sources not exploited by the bee. He is inclined to accept the latter alternative, because the honey he analyzed had been stored during the winter. He loses sight of the fact that in Lower California there are always some flowers in bloom during the winter. It seems more probable, therefore, that *Polistes* merely regurgitates the collected nectar into its cells without being able to alter its chemical constitution.

For further light on the instincts of *Polistes* we have to turn to the tropics, especially to America, where we find the metropolis of this and the allied genera of social wasps. Here, in contrast with the single genus *Polistes* represented by a very small number of species in Europe and the United States, we find according to the recent studies of R. von Ihering[3] and Ducke,[4] no less than eighteen genera (*Melissaia* [=*Nectarina*, *Caba*], *Pseudochartergus*, *Chartergus*, *Clypearia*, *Charterginus*, *Paracharterqus*, *Polistes*, *Monocanthocnemis*, *Mischocyttaris*, *Synœca*, *Synœcoides*, *Tatua*, *Apoica*, *Leipomeles*, *Polybia*, *Metapolybia*, *Protopolybia*, and *Megacanthopus*), with more than a hundred described species from Brazil alone. This series of

[1] Note sur les Hyménoptères du Genre Polistes recueillis par M. Diguet en Basse-Californie. Bull. Mus. d'Hist. Nat., 1895, p. 37, 38.

[2] Examen du Miel Produit par une Poliste de Basse-Californie. Bull. Mus. d'Hist. Nat., 1895, pp. 38, 39.

[3] As Vespas Sociaes do Brazil: Revista do Museu Paulista, VI, 1904, pp. 97-309, pll. III-VII.

[4] Sobre as Vespidas Sociaes do Pará. Bol. Museu Goeldi., III, 1905, pp. 317-374, pll. I, II.; Prim. Supplemento *ibid.*, IV, 1906, pp. 652-698, pll. I-IV.

forms embraces 17 species of *Polistes* and 36 species of the closely allied genus *Polybia*. All of these insects construct nests with paper combs, and species of several of the genera have long been known to provision these with considerable quantities of honey. Both H.[1] and R. von Ihering[2] have contributed some valuable observations on this and other habits in these insects. Very little honey and that only in drops is stored up by the Brazilian species of *Mischocyttaris* and *Polistes*, but *Melissaia mellifica* provisions its combs with large quantities of this substance. This is true also of *Polybia sericea*, *sylveiræ*, *edula*, *occidentalis* and *lechuguana*.

I find in the American Museum of Natural History a large nest of the Mexican *P. occidentalis pygmæa*, donated to the institution by Mr. William Schauss. It is subglobular, about 20 cm. in diameter, of a light ochre brown color and attached to the small branches of a tree. It contains several combs placed one above the other, each comprising hundreds of cells 2.5 mm. in diameter and about 5 mm. deep. The lowermost combs have been removed and many of the upper combs cannot be seen without destroying the outer paper envelope, but each of the visible combs has the cells over a large central area filled with nearly mature larvæ and pupæ. Around these there is a zone of empty cells and then follows, next to the wall of the nest, a zone 2-3 cm. broad of cells filled with a dark brown, inspissated honey of agreeable flavor. According to Mr. Wm. Beutenmüller, the lowermost comb, when removed some time ago, contained no brood but was filled with honey even in the centre. This nest therefore resembles a beehive in having the brood cells in the centre both of the individual combs and of the series of combs, and the honey cells on the periphery.

The honey of the South American wasps seems to be highly toxic, at least in certain localities or in certain seasons. Azara[3] describes cases of poisoning from the honey of the tatú wasp (*Tatua morio*, according to H. von Ihering) and Auguste de St. Hilaire[4] gives a vivid account of the effect on himself and two companions of eating the honey of the lechuguana wasp (*Polybia lechuguana*) in Uruguay. On this occasion the honey produced pain in the stomach and intense cerebral excitement followed by drowsiness and excessive debility.

The great quantities of honey collected by the tropical wasps are, of course, stores of provisions for the winter, for, as the von

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[1] Biologie der stachellosen Honigbienen Brasiliens. Zool. Jahrb. Abth. f. System. XIX, 1903, pp. 179-287, pll. X-XXII, 8 textfigg.

[2] *Loco citato*.

[3] Voyages dans l'Amérique Méridionale, V, 1, 1809, p. 160.

[4] Relation d'un Empoisonnement causé par le miel de la Guêpe Lecheguana. Ann. Sci. Nat., IV, 1825. pp. 340-344.

Iherings have shown, many of the species, unlike the northern *Polistes*, do not abandon their nests on the approach of the unfavorable season and start new ones in the spring, but continue to add to their combs and keep on raising their brood throughout the year. These naturalists are unquestionably right in deriving the conditions seen in our northern *Polistes* from those of the tropical species. There can be little doubt that *Polistes* has extended its range into North America and Europe since the close of the glacial epoch. The storing of honey for the winter has been discontinued and the life of the species has been saved by a new set of adaptions involving the abandonment of the nest, the temporary suspension of the breeding instincts and the hibernation of a small number of fertilized females. The drops of honey occasionally stored in the nests are all that remains to point to a once very important means of tiding over the flowerless season and preserving the life of the individual colony. Rouget, Brongniart and myself have observed this vestigial instinct only in the autumn, and this would seem to be the most likely time for a feeble display of the old habit. Marchal observed it in the spring. In this case the instinct may have been resuscitated by a protracted spell of cold weather, scarcity of flowers or other conditions simulating the oncoming of winter.

Not only has the honey-storing instinct of our northern *Polistes* been reduced to a feeble and useless vestige by the adaptation of this insect to life in a temperate zone, but the nest-building instincts, when compared with those of the allied tropical wasps, show unmistakable signs of a similar degeneration. In *Polybia* and several other genera the nest consists of a number of combs, each comprising hundreds of cells and the whole is enveloped in a paper involucre as in the circumboreal genus *Vespa*, but in *Polistes* the involucre is no longer constructed and the nest has dwindled to a single comb with comparatively few cells. And this reduction in the size of the nest has led to, or is the result of, a reduction in the size of the colony.

Non-social insects also occasionally exhibit vestigial instincts of nidification. Schröder[1] has recently obtained experimental proof of the existence of these in the caterpillars of a Tineid moth (*Gracilaria stigmatella*), an insect which feeds on the willow and for this purpose conceals itself in a little case made by folding the point of the willow leaf over onto the under side, curling it up and closing any openings with silk. Schröder reared a brood of caterpillars and placed them on willows with

[1] Ueber experimentell erzielte Instinkt-variationen. Verhand. deutsch. Zool. Gesell. 1903. pp. 158-166.

the tips of the leaves cut off or on trees with leaves of a different shape. He found that 84 out of 91 individuals thus deprived of the opportunity of constructing their cases in the normal manner, built cases by rolling up the edges of the leaves. A second generation bred from these insects on leaves with their tips cut off, behaved in the same manner. A third generation was then bred on uncut leaves and of the 19 cases constructed 15 were of the typical or normal form (*i. e.*, with the tip of the leaf folded over), but four were made by rolling up one or both edges of the leaf. From these experiments Schröder concludes that "when the spinning glands are exhausted or when there is no opportunity to construct the case in the typical manner, phylogenetically older instincts, which are still manifested by other species of the genus, are released. Even still older instincts, in fact, the most primitive instincts of the microlepidopterous larvæ, may manifest themselves, as when the larvæ merely conceal themselves between leaves loosely drawn together. Such modified instincts may be repeated by the offspring without a repetition of the stimulus which first caused their appearance."

In the following example we see another simple instinct emerging under very definite conditions that closely simulate the conditions under which the creature's ancestors once lived. The common pond-snails of the genus *Lymnæus* live in shallow water and breathe atmospheric air by means of a lung, *i. e.*, a sac whose walls are lined with blood-vessels. And although these snails are able to take up directly through their integument the oxygen dissolved in the water, they are nevertheless compelled to rise to the surface and renew the air in their lungs at intervals varying from fifteen seconds to several hours, except during the first days of their lives, when they obtain all their oxygen directly from the water.[1] Many years ago F. A. Forel,[2] von Siebold[3] and Pauly[4] found living at the bottom of lakes in Bavaria and Switzerland certain *Lymnæi* that could not, for very obvious reasons, come to the surface to breathe. Forel noticed that snails brought up from a depth of 250 m. in Lakes Leman and Constance had their lungs filled with water, showing that these animals had long since aban-

[1] Walter, The Behavior of the Pond Snail Lymnæus elodes Say. Cold Spring Harbor Monographs VI, March, 1906. pp. 35.

[2] Introduction à l'étude de la faune profonde du lac Léman. Bull. Soc. Vaud. Sci. Nat. X, No. 62, 1869, and Materiaux pour servir à l'étude de la faune profonde du lac Léman. *Ibid.* XIII, No. 72, 1874.

[3] Ueber das Anpassungsvermögen der mit Lungen athmenden Süsswasser-mollusken. Sitzb. math. phys. Cl. K. Akad. Wiss. München 1875, Heft I.

[4] Ueber die Wasserathmung der Limnæiden. Gekrönte Preisschrift. München 1877, pp. 47.

doned the typical pulmonate method of respiration. But when these same snails were placed in shallow water they repeatedly rose to the surface and filled their lungs with air, like the common pond snails. Similar observations were made by Pauly on the snails of Lake Ferchen. These, in fact, definitively abandoned the habit of breathing water with their lungs after they had once had an opportunity to reach the surface. Here we have a sudden adaptation to new conditions in the life of the animal through the artificial resuscitation of an instinct that for generations has been kept in abeyance, an instinct which might properly be designated as vestigial if it were not so perfectly manifested.

A search through the extensive literature of animal behavior would probably yield many additional examples of obsolescent instincts, but the foregoing will suffice for present purposes. They point to the following conclusions, which, I believe, should not be overlooked in the study of comparative psychology.

1. The vestigial instinct action presents itself as an act of racial or phyletic recollection (Mneme, in the sense of Semon[1]) and must, like the representations of individual memory, depend on psychophysical dispositions abiding in latency, just as the visible morphological characters of the adult organism arise from invisible physiological dispositions in the germ-plasm. These dispositions must be inherited with great tenacity and persistency, since vestiges, both instinctive and structural, often remain latent for generations and then suddenly manifest themselves under the stress of extraordinary stimuli.[2] I am not here concerned with the nature of these dispositions in themselves, for they belong to the category of hypothetical postulates or constructions and at present answer their purpose if they enable us to subsume such apparently disparate phenomena as heredity, racial and individual memory under a common point of view.

2. The vestigial instincts obviously represent a part of the

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[1] Die Mneme als erhaltendes Princip in Wechsel des organischen Geschehens. Leipzig, Wilh. Engelmann, 1894.

[2] Many of these vestigial manifestations may therefore be regarded as cases of atavism, when they fail to reappear in all generations, but I have avoided the use of this term, because, as Emery has shown (Was ist Atavismus? Verhandl. V. Internat. Zool. Congress. Berlin, 1901 [1902]) it may be understood in two different senses, either as the reappearance by discontinuous heredity of peculiarities belonging to remote ancestors, or as a special potency or faculty which brings about such reappearance. There can, of course, be no objection to the use of the term in the former sense, but its employment in the latter has had a tendency to discredit the whole subject of discontinuous or latent heredity.

animals' endowment, and their manifestation shows that the capacities of even the lower organisms are greater than their ordinary routine behavior might lead us to suppose. I am not aware that any teleological interpretation has been offered for the marvellous persistency of vestigial instincts and structures. At first sight such a conception would seem to involve a contradiction, since it is usually supposed that these vestiges are functionless and purposeless. If all we mean by these words is being no longer able to respond adaptively to a particular set of conditions, the vestigial organ or instinct may indeed be said to conform to this definition. In this sense the honey storing of *Polistes metrica* as an instinctive response to the cold of autumn, is quite purposeless. But there is another and broader sense, in which such vestiges assume a very different dignity. The organism can exist only in a cosmic setting, and this setting is continually and sometimes suddenly changing. Conditions that have once existed may and often do recur after long lapses of time, or what may amount to the same thing, the organism may migrate or extend its range into regions like those inhabited by its remote ancestors. When this occurs a stock of instinct relicts may be of the greatest utility to the organism, for the persistent inheritance of enfeebled tendencies and impulses may then make possible rapid readjustments to the new conditions. For example, if our winters should become milder, or if *Polistes* should extend its range to such subtropical islands as the Bermudas or the Azores, a manifestation of the latent and enfeebled honey-storing instinct might acquire the value of an incipient adaptation and enable the species to survive under conditions unfavorable to hibernation. Similarly, if the Swiss lakes should become shallow through sudden upheaval of their floors, the deep water *Lymnæi* could at once revert to the respiratory habits of their paludicolous ancestors and, should the desiccation continue, they might even become terrestrial like the land Pulmonates. This last possibility suggests that even when conditions merely change without recurring, vestigial organs and instincts may be useful as starting points for entirely new adaptations, for there are not wanting cases of vestiges that have acquired new functions. In our common Dipterous flies, *e. g.*, the halteres, or vestiges of the posterior wings have become sense-organs since they ceased to reinforce the action of the anterior wings in flight; and the vermiform appendix of man is said to have acquired the function of an intestinal tonsil.

3. The foregoing and similar considerations lead me, in conclusion, to a few remarks on the method of studying vestigial instincts and instincts in general. Some Germans and their over-zealous followers in other lands, have come to look

with a certain disdain on all methods of biological research not strictly experimental. I am, of course, willing to concede many of the claims of these authors. It is evident that in all cases like those above cited, vestigial instincts become manifest through the incidence of unusual conditions. When such conditions intervene in the natural environment of an organism, we have one of nature's experiments, when they are devised and applied by the investigator we have the laboratory experiment, but in both cases the emerging instinct can be correctly understood only by an application of the comparative and historical methods. Thus, as we have seen, the honey-storing instinct of our northern *Polistes* cannot be satisfactorily interpreted without recourse to a study of the whole genus or family to which the insect belongs, and a comparison of the instincts displayed by the various species in their normal environment. And the sudden change in the respiratory instincts of the deep water *Lymnæi* is quite incomprehensible without a reference to the habits of the shallow water and terrestrial Pulmonates. The necessity of applying the comparative and historical methods is also shown in many negative cases. When we ask, *e. g.*, why our domestic pigeons no longer alight or nest in trees, or do so only in very rare instances, no amount of experimentation on the nesting habits of these birds can assist us in answering this question. A comparative study, however, shows that the domestic bird is in all probability derived from the rock-pigeon, a form that had developed an instinct to alight and nest only on cliffs or open ground, and this peculiarity, granting the wonderful conservatism and other peculiarities of hereditary transmission, accounts for the negative behavior above mentioned. Similarly, an explanation of the remarkably small size of the colonies of the northern *Polistes*, as contrasted with the populous communities of the tropical *Polybia* and the allied genera, can be obtained only from a comparative phylogenetic study of the various social wasps with reference to their present natural environments. The tendency of some of our workers in animal behavior to pick and choose single, convenient forms for study—a legacy of the morphological regime which has held sway in our biological laboratories—is therefore unfortunate to the extent that it narrows the field of inquiry of the individual investigator. I am convinced that our knowledge of many of the aspects of instinct, like the one I have been considering, would gain immensely by the comparative study of whole genera or families of closely related organisms, for we know of no case in which an instinct is peculiar to a single species (unless it be, perhaps, the human instinct of reason), and of no cases in which two species manifest an instinct in precisely the same manner.

ATTENTION AND INTEREST[1]

By William H. Burnham

It was said by the older psychologists, and is repeated to-day, that attention depends upon interest. Nobody denies the truth of this statement, but it is a survival of a psychology fast becoming obsolete. It is equally true and quite as important that interest depends upon attention. The word interest, as everybody knows, is used in two senses:—first, as practically all psychologists agree, it denotes a complex state of feeling; second, it denotes a permanent mental possession—as when we say a man has an interest in art, or literature, or music, or the like. What is meant is that one has a store of associations related to these subjects, that he is in the habit of attending to them; or better, as an essential element in attention is preperception, that one has a permanent habit of preperception in such subjects. These two meanings of the word interest are as different as they can well be—the one a temporary affective state, the other a permanent habit of preperception. But, as it seems, even in our standard psychologies these two uses of the word are often confused. Fortunately, perhaps, for the preservation of my friendships time is lacking for concrete illustration.

If the word interest is used in the latter sense, to signify a permanent habit of preperception, nobody will deny that attention depends upon interest; but this is merely saying that our present preperception depends upon our past habits of preperception. If, however, by interest is meant the affective state, it is not in harmony with modern psychology to say that attention depends upon interest. Psychologists are coming apparently more and more to the view that every reaction of the organism contributes its increment, however infinitesimal, to the affective life of the individual. The organic adjustments in the case of attention are no exception. They contribute their increment of feeling. The resulting affective state is interest.

All writers are agreed that physical reactions of varied character are the necessary conditions of attention; all agree that interest is an affective state. Modern investigation has amply demonstrated the physiological conditions of attention, sensory, motor, vasomotor, circulatory, respiratory, visceral. Why

[1] This paper is printed substantially as presented at the Cambridge meeting of the American Psychological Association, Dec., 1905.

should not this organic adjustment be correlated with an affective state of consciousness? What is this affective state but interest? The theory I would present is simply this: The feeling of the organic adjustment in attention is the interest. Attention is a fundamental reaction of the whole organism, comparable to the tropisms of plants and animals. As Professor Royce puts it: "Whoever is persistently attentive is expressing an attitude of the organism which has the essential character of the now frequently mentioned tropisms.[1]" The correlative of this is interest. Whenever we turn attention to a subject, we have a feeling called interest. While it might be vain to attempt to show the primacy of one or the other of these correlatives, the facts, in the writer's opinion, are described more accurately by saying that interest depends upon attention than by saying that attention depends upon interest.

This, it may be said, is a mere theory, what is there to demonstrate it? This is a fair question. The answer is that it cannot be demonstrated. But what is the opposite doctrine but a mere theory? It has been assumed, but no one has attempted to demonstrate it. If the primacy of either is to be asserted, the presumption is in favor of the theory that interest depends upon attention. Why should interest stand alone without physical cause, when other affective states are correlated with physical reactions? On the other hand, why should not the organic changes involved, as everybody knows, in attention, the so-called conditions of attention, have their mental correlative in some such affective state as interest? Stated in this way the theory suggested can be held by psychologists with widely different views of feeling. Stated as before,—the feeling of the organic adjustment is the interest,—it is practically a corollary from the Lange-James theory of emotion. In my opinion quite as good a case can be made for the latter as applied to the subtle feeling of interest as in the case of the coarser emotions.

This view of interest has been approximated or anticipated by a number of psychologists, among them, if I mistake not, Prof. Titchener, and Prof. Dewey, and of course by all those who identify attention and interest. Of the last mentioned theory Miss Calkins has given an excellent statement. She rightly says that a thing attended to is interesting, and she makes interest and attention synonymous. We may, I think, carry our psychological analysis a little farther. Even "what God has joined together" psychology is sometimes justified in separating. The relation of attention to interest is such a case. And if for no better reason than to protest against the

[1]Outlines of Psychology, p. 329.

prevailing confusion of the psychology of attention, it would be well to emphasize the organic adjustment as the basis of interest and feeling, and attention as primary.[1]

With this view of interest, the traditional conundrums are explained quite as well as by any other. The pages of the older psychologies were enlivened by thrilling stories of certain orators who, in the passion of eloquent gesticulation, severely wounded their hands on desk or pulpit, but remained unconscious of the fact until their effort was over. The theory here suggested, together with the well-known law of the relativity of feeling, offers a plausible enough explanation of such cases. The intense interest caused by the orator's intense attention so filled consciousness that the pain was excluded; the interest was the stronger affective state. Afterwards, when the orator's intense attention ceased, the interest ceased also, and the pain of the wound was felt.

It has been something of a psychological puzzle that attention weakens feeling. There is no question that it does. If one gives close attention to a pain, for example, the pain is appreciably diminished, and illustrations have been furnished by experiments in the laboratory. Kuelpe states this effect upon the feelings as follows: "While pleasure and pain are brought far more vividly to consciousness by concentration of attention upon their concomitant sensations, they disappear entirely if we succeed (and we can succeed only for a moment) in making the feeling as such the object of attentive observation."[2] Now, if the feeling we call interest is the result of attention, then by the very act of giving attention to a pain we arouse a new feeling that on account of the limitations of consciousness and the law of relativity weakens the former painful feeling; and, if this attention and its concomitant interest are sufficiently intense, they may submerge the pain altogether.

It is often said that interest is contagious. This is a very pretty metaphor and it has long done service in psychology, but no one has isolated the bacillus of interest that causes the contagion, although psychologists seem to have been satisfied with the metaphor. Dropping the figure let us ask how the interest spreads. The following simple hypothesis seems to accord with the facts. One person becomes interested. His

[1] Since presenting the above paper before the American Psychological Association, the writer has noted the statement by Prof. Pillsbury, which he had not read at the time: "Things are only interesting because we turn our attention to them, but we do not turn our attention to them because they are interesting." But as I understand the context, he does not acknowledge the relation of interest to attention involved in this statement. L'Attention. Paris, 1906. pp. 72.

[2] Psychology, p. 430.

enthusiasm *suggests* in obvious as well as subtle ways that the subject is worth giving attention to. Forthwith others imitate his example and attend to it, and interest follows as the result, first the affective state, then the habit of preperception.

Probably a similar theory accounts in whole or in part for the well-known fact that we are often interested in the disagreeable or the painful; for the spread of fads in a community; for the fact that intense attention often hinders perception and action; for anæsthesia due to hypnotic suggestion, etc.

To résumé briefly: The word interest as we have noted is used in two senses: 1st, to denote our permanent habits of preperception; 2nd, to represent a temporary affective state complex in character. Attention is a reaction of the whole organism, comparable to the tropisms of plants and animals. We must suppose an affective state correlated with this reaction. This affective state is interest. The least we can say in this case is that interest is correlated with attention.

While with legitimate heedlessness we may continue to use the popular phraseology in regard to attention and interest—just as we say the sun rises and sets—in our special psychology of attention it is misleading to teach that attention depends upon interest. If we use the word interest in the sense of a permanent habit of preperception, what we mean is that our attention of the moment as preperception depends on our habits of preperception; but if that is our meaning, we should say so. If, however, we use the word interest in the other sense, meaning the affective state of the moment correlated with attention, to say that attention depends upon interest is not in harmony with modern psychology.

Not only the popular use of the words interest and attention but our psychological usage as well, are misleading survivals of an obsolete psychology. In pedagogy this usage has led to much confusion and error. There are actually two opposing camps—those who believe in the moral value of the uninteresting, and those who believe in the pedagogical value of the interesting. It is said by one side that only by giving attention to the uninteresting can the power of voluntary attention be developed. It is said by the other that only when interest is appealed to can a child's attention be gained. To attempt a reconciliation would be a case of crying peace! peace! when there is no conflict. Both are largely right: for so far as interest means preperception, attention is impossible without it; the child's mind can no more give attention to the absolutely uninteresting in this sense than the eye can perceive the ultra-violet rays of the spectrum; while so far as interest means feeling it is bound to come any way when attention is actually turned to an object.

Of course, any such account of the processes of attention and interest does injustice to the complexity of the actually existing mental states. The process of preperception determines not merely the aspects of an object to which we attend, but to a great extent the intensity and coloring of the affective state, that is, the interest in this sense. That this may occur in a short circuited manner, the preperceptive images being associated with affective states, or if one prefer, they themselves having an emotional coloring, there seems no reason to deny.

The view here presented has been stated with somewhat arbitrary simplicity. If to some the whole matter seems too obvious to be worth presenting, and if to others it seems reactionary, this may be an illustration of what has been said of the prevailing confusion in the use of the word interest.

NOTES ON SOME ASPECTS OF THE FOLK-PSYCHOLOGY OF NIGHT

By ALEXANDER F. CHAMBERLAIN

The author has no intention at present of furnishing a monograph on the psychology of night; he has simply put together some notes on certain aspects of the subject which have seemed to him worthy of more extended investigation by the psychologist, aspects which in previous studies have perhaps not received due attention,—the ethnologic and folk-lore material relating to night and the reactions to it on the part of the various races of man, civilized and uncivilized, contains much of interest and value to the enquirer into the origin and development of human mental phenomena. Certain large sections of the subject such as night and religion, sleep, dreams, fear, the emotions, etc., some of which have been much discussed by other writers, are here but lightly touched upon or reserved for future consideration.

1. *Night and Death.* In the minds of many peoples, civilized and uncivilized, night and death are commonly and inseparably connected,—night, as the time of the absence or the disappearance of light, being conceived of as a period of death, or, at least, of lethal significance. This correlation of life and light, of night and death, is implied in the word *night* itself, which, with its cognates in various European tongues (German Nacht, Latin nox, Greek nux, Sanskrit nakta, etc.), seems connected with certain terms for "death" (*e. g.*, Latin nex; Greek nekus, "corpse;" Sanskrit nac, "to perish"), etc. The common saying "the dead of night" belongs also here, with other kindred expressions. In classical mythology, Nox and her brother Erebus are the children of Chaos, and one of her own offspring is represented as "black death," while she is often referred to as "the mother of death," and likewise of sleep (regarded as the brother of death). But night has also been looked upon as "the mother of man," and "the mother of all," out of whose fertile womb came life itself and all existing things in the universe. That the emphasis upon the lethal character of night and its antagonism to life has been exaggerated, appears from both negative and positive evidence.

Suicide, the most anti-individualistic form of death, seems to prefer the day. Of 8,226 cases, *e. g.*, occurring in the United

States during the six years 1882-1887, the great majority took place in day-time, only 2,419 being recorded at night. Later statistics do not appear to have altered this relation much, if any.

Geck, who has studied the distribution of 100,000 cases of suicide occurring in Germany during the 20-year period 1876-1895, finds an increase paralleling the length of the day, reaching a maximum in June and a minimum in December. The same relation holds if this period is divided into four sections of five years each. A previous investigation by K. Becker, covering 87,439 cases during the period 1872-1885 in Prussia, Saxony, Würtemburg, Baden and Hamburg, confirms Geck's results. Here, too, a division into three shorter periods shows no difference of any significance. Even discounting for the general difference of summer and winter months, and for the increased facilities for self-destruction offered by day-time, there yet remains something in these figures which argues against the theory of the death-influence of night. The same conclusion applies to other forms of death than suicide, similar allowances being made for the industrial, social and other factors more potent during the reign of day.

Statistics of deaths indicate a decided preponderance in day-time. Raseri, whose investigations dealt with 25,474 cases, found the maximum of deaths to occur in the period between two and seven o'clock in the evening, and the minimum during the last hours before midnight.

Night and death have been made much of in literature and art among many peoples, but it was reserved for Joseph Blanco White (d. 1841) in his famous sonnet *Night and Death* to say the genius-word:

> Mysterious Night! when our first parent knew
> Thee from report divine, and heard thy name,
> Did he not tremble for this lovely frame,
> This glorious canopy of light and blue?
> Yet 'neath a curtain of translucent dew,
> Bathed in the rays of the great setting flame,
> Hesperus with the host of heaven came,
> And lo! Creation widened in man's view.
> Who could have thought such darkness lay concealed
> Within thy beams, O Sun! or who could find,
> Whilst flower and leaf and insect stood revealed,
> That to such countless orbs thou mad'st us blind!
> Why do we then shun death with anxious strife?
> If Light can thus deceive, wherefore not Life?

The individual bard thus agrees with the folk-poets of many lands in seeing the life that lies in night rather than the death so often inseparably connected with it in human thought. Light and life are thus alike in being born of night.

2. *Night as Mother. Night and life.* Both in the personi-

fication of night in mythology and in the figurative language of poetry the idea of motherhood is prominent. The ancient poets styled her "mother of all things, of gods as well as of men," and in classic mythology she appears as mother of day and light, of the fates and the furies, of the hesperides, of death, sleep and dreams, of discord and strife, of hunger and fear, of nemesis, of satire and fraud, etc. In primitive thought darkness and night, like earth, seem inevitably linked with motherhood. The womb of woman and the womb of night are credited with close and primeval kinship. Milton's figure of "the wide womb of uncreated night" had its savage and barbaric predecessors; so, too, with Whittier's "the night is mother of the day," for, before him, the classic poet had said, "out of night is born day, as a child comes forth from the womb of his mother." Bachofen, the protagonist of the "mother-right" theory in the last century, observed that "motherdom is related to the idea of the day-bearing night, as fatherdom is to light sprung from the union of the sun with mother night." Sometimes the light born of night is so pre-eminent and predominant as to subdue, expel, or destroy all her other evil brood, and we have the undisputed omnipotence of him who is light, and in whom "is no darkness at all."

The folk-idea of "mother" night receives some support from the incidence of human birth, for vital statistics produce not a little evidence in support of the view of Berlinski that night is distinctly favorable to individual life. Birds are said to break from the egg more commonly during the night or early morning. The same is said to be true of birth with many species of animals, and the tendency among human beings seems also to be born at night, or in the early morning. Dr. V. Goehlert's investigation of the hourly distribution of 86,850 births occurring in the Canton of Zürich, Switzerland, during the years 1876-1884, shows a maximum between 12 P. M. and 2 A. M. and a minimum between 12 M. and 2 P. M. The percentages for four-hour periods were as follows: from 12 M. to 4 P. M., 14.33%; 4-8 P. M., 15.01%; 8-12 P. M., 16.56%; 12 P. M.-4 A. M., 19.66%; 4-8 A. M., 18.68%; 8 A. M. to 12 M., 15.76%. Observations in Brussels, Berlin, Hamburg, Dorpat, Edinburgh, at varions dates from 1811 to 1884, substantiate the conclusions of Goehlert. In Dorpat (Livonian Russia) out of 25,382 births during the period 1850-1881, the maximum (40%) for six-hour periods was between 12 P. M. and 6 A. M., and the minimum (12.8%) between 12 M. and 6 P. M. Raseri's examination of the time of birth in 36,515 cases also confirms Goehlert's views, the maximum occurring in the early hours of the morning, the minimum during the first hours of the afternoon. The evolutional defences of life at night are in evidence also, although

not much attention has been paid to them by biologists and students of the animal world. Verrill has recently, however, pointed out some of the nocturnal protective colorations of mammals, birds, fishes, insects, etc. Nature, it seems, shows herself here quite as skillful in protecting her creatures by assimilating their colors and markings to the nightly environment, as she is in the devices she has evolved for ensuring their safety by day.

3. *Night and the dead.* That the spirits of the departed visit at night their former home, gather about the hearth and enjoy themselves in their own way is a folk-belief widespread among the peasantry of Europe,—a belief that has led to many curious and significant customs. Often (as, *e. g.*, in Brittany) the fire must never be allowed to go completely out so that the returning spirits may warm themselves,—or sometimes it is the *Bouffon Noz* (farceur de nuit), or the Virgin herself who comes. And, when the fire has been used to cook the pap for a newborn child, it must be kept up all night so the Virgin may come and get ready the food of the little Jesus. In Brittany the fire is kept up at night by a log called *kef an anaon* ("the log of the dead"). In certain parts of the Vosges country, during the week of All Saints, the windows are opened and the covers of the beds turned down so that the dead may for a brief space sleep in their old place. The philosophy of the "house spirits," and "ancestor worship," looms large here. As day belongs to the living, night belongs to the dead; the bright, crackling fire to men and women of this world, the smouldering embers at least to those who "revisit the glimpses of the moon." This innocuous, friendly and sympathetic side of spirit-visitancy is but one of the attempts made by man to humanize the world beyond the grave and to attach it to himself as part of himself,—to make the immortals mortals again.

After being built, houses are subject to certain ceremonies not alone among savage and barbarous peoples, but also among civilized and Christian nations, with the object of preserving them from the inroads of spirits, especially during the hours of darkness. Similar precautions were and still are taken, in certain parts of the globe against the inroads of the devil and his imps, who preferred the night for their interference with the happiness of men and women. Here belong the harriers of the air, the wind spirits, "wild huntsmen," "night-goers" (with innumerable names), and death, himself, who "rides by night." And against "the pestilence that walketh in darkness," man has continually to guard himself and what is his.

Beautiful, indeed, and thoroughly worthy of the human heart, are some of the household beliefs and practices connected with the "feeding of the dead" and the entertainment in most hos-

pitable fashion of the nightly visitants, who seek so eagerly the scenes of their former existence. Sacred are the thirst and the hunger of the dead; and blessings innumerable flow from their happy spiritual touch. Their gifts are often not to be feared in the least, and their comings and goings are the fortune of their descendants. In what happy touch the living are with the "good dead," one can learn in some region of peasant Europe, a corner of Brittany, for example. The dark side of the picture may be sought in some part of Malaysia, where every soul alive is in endless fear of the roving spirits of the departed.

Against the malevolent spirits of the dead who fill the air of night manifold precautions have to be taken and the ingenuity of man is wearied in efforts to lay these terrors of his environment, who are bold enough sometimes to harrass him even in the broad light of day. For many peoples (not savages and barbarians of the lowest type alone)

> "Millions of spiritual creatures walk the earth
> Unseen, both when we wake and when we sleep."

Not merely this, but in the fearsome night they are seen and terrify the heart and mind and soul of man, till fear itself creates unfear and brings release. But not before innumerable petty and many genial devices have been adopted.

4. *Night as the "evil time."* According to the Andaman Islanders, a very primitive people of Negrito stock, Puluga, the uncreated and immortal creator of all things, who lives in the sky, "is omniscient only while it is day, when he can see." In the darkness of night this faculty leaves him. Where the deities of day and night are not especially arrayed in opposing orders or classes, it often happens that the overruling powers lose wholly or in part their strength during the hours of darkness. This idea finds expression in the saying that "God loses to the devil at night." And in this riot of evil man is often easily involved. The individual and the general thought is well expressed in Hamlet's famous words:

> "'T is now the very witching time of night,
> When churchyards yawn, and hell itself breathes out
> Contagion to this world: now could I drink hot blood,
> And do such bitter business as the day
> Would quake to look on."

And, earlier in the play, the ghost of Hamlet's father, to whom his son had said:

> "Be thou a spirit of health or goblin damn'd,
> Bring with thee airs from heaven, or blasts from hell,
> Be thy intents wicked or charitable,
> Thou comest in such a questionable shape
> That I will speak to thee,"

tells him:

> "I am thy father's spirit,
> Doom'd for a certain time to walk the night,
> And for the day confin'd to fast in fires,
> Till the foul crimes done in my days of nature
> Are burnt and purg'd away."

And the unpublished volumes of the folk-lore of innumerable tribes of man are filled with the record of the words and deeds of the "perturbed" spirits who cannot "rest." And this same literature reveals the existence in times past and in times present of hundreds of "night taboos," prohibitions of acts that, when performed after sunset, or during the hours of darkness, alarm and irritate the spirits of the dead and bring upon the doer their enmity in innumerable ways, stir up to activity the demons of the air, etc., and particularly the prince of darkness, whose "name is legion."

The following, cited by van Gennep, will serve as typical night-taboos (they are from the aborigines of Madagascar):

1. The house must not be swept at night,—that would bring poverty.
2. One must not comb the hair, wash the face, or cut the finger-nails at night.
3. One must not call out, whistle, or carry mutton at night, else the spirits will pursue him.
4. One must not go to bed without having a light in the room,—otherwise he would resemble the dead in the tomb.
5. Ashes or dirty water must not be thrown away at night,—that displeases the spirits much.

It will be seen that the night-lore of these peoples often resembles, or is even identical with, that of our own race. In various parts of France folk-belief forbids sweeping house after sundown, lest some one of the family should die. In the Breton region of the Côtes-du-Nord the reasons assigned are that the souls of the dead who come to visit their old homes during the night are in danger of being swept out with the dust, or the Virgin Mary, who is seeking houses in which to lodge her favorite souls, may be driven away. In some places it is only on the eve of the feast of the dead that this taboo holds,—for fear of driving off the souls of those in purgatory.

Leaving a light burning is not always due, however, to fear of the devil or regard for the spirits, but may sometimes be accounted for from simple economic or social reasons.

Civilized peoples, outside of individual idiosyncrasies, take their sleep in darkness, not leaving lights burning in their bedrooms. This is not, however, the case with all primitive peoples. The Eskimo, notably, as Nansen has remarked, "do not sleep in the dark like other people," the lamps being kept burning all the time in the *iglu* or snow-hut. This custom,

Hough thinks, may be due in part to their high appreciation of "the feeling of companionship, security or sociability, given by light," and partly also to "the inconvenience of rubbing out fire with the fire-drill to relight the lamps." The long winter-darkness and the added obscurity of the low *iglus* make necessary, profitable and pleasurable the turning of night into day.

Among French folk beliefs as to the night-comings of the devil are these:

1. If a chair or a stool is left upside down the devil will come.
2. If any one goes to bed without moving the chair on which he sat when taking off his shoes, he will be visited by the devil.
3. If a woman looks at herself in a mirror after sun-down, the devil will appear.
4. If dances at farms and in inns do not stop at midnight, the devil will come and take part.
5. The devil will appear to those who talk too much about him after sundown.
6. Whistling or singing outside the house at night attracts the devil.
7. If on hearing a noise at night one turns his head, the devil seizes the occasion to injure him.
8. To make the sign of the cross after sunset will bring on the devil.
9. To work in the fields at dark of night will cause the devil to appear and carry off the laborer if he persists in his toil.
10. If a woman with child goes out after twilight, the devil will take possession of her offspring.
11. Women just after child-birth and children before baptism must not be out at night because the devil roams about from one *Angelus* to the other.
12. After sunset, no woman must go abroad carrying in her arms a child of less than a year or one not yet weaned, else the devil will twist its neck, flatten its head, or carry it off altogether.
13. When women give birth to children at night, the chorus of devils sings above the houses.

Many of these things apply as well to evil spirits other than the devil, to the spirits of the dead, to goblins and monsters of all sorts, to witches, sorcerers and other malevolent beings, who are most active and most dangerous to mankind during the hours from dark to dawn. Curiously enough, the Chinese, whose ideas are so often quite the reverse of ours, believe that "the gods walk abroad by night," and with them night, as the poet Young has termed it, is, "the felt presence of the Deity." But, even with us, the power of evil is sometimes shorn of its nocturnal strength.

In the play of *Hamlet* (Act. 1, Sc. ii), after the exit of the Ghost, the following conversation occurs:

Ber. It was about to speak when the cock crew.

Hor. And then it started like a guilty thing
Upon a fearful summons. I have heard

The cock, that is the trumpet to the morn,
Doth with his lofty and shrill-sounding throat
Awake the god of day, and at his warning
Whether in sea or fire, or earth or air,
The extravagant and erring spirit hies
To his confine: and of the truth herein
This present object made probation.

Mar. It faded on the crowing of the cock.
Some say that ever 'gainst that reason comes
Wherein our Saviour's birth is celebrated,
The bird of dawning singeth all night long.
And then, they say, no spirit dare stir abroad,
The nights are wholesome, then no planets strike,
No fairy takes nor witch hath power to charm,
So hallow'd and so gracious is the time.

Hor. So have I heard, and do in part believe it.

Night, in the old heathen days, was the time for the deeds of "extravagant and erring spirits," of sea, fire, earth and air, of fairies "take" and witches' "charm," and it is an evidence of the impression made upon the folk-heart of Europe by the story of Bethlehem that at the "hallowed and gracious" time of the birth of Jesus all these evil powers had their activities temporarily annulled. The advent of dawn had rendered them powerless before, but now the coming of the infant Saviour stemmed the tide of their life at its most approved epoch. Surely the "Holy Night" was well thought of among men. The folk-lore of the "cock-crow" and of the "Holy Night" deserves special treatment and are too voluminous to be considered here. A whole book might perhaps be written on the single topic of the Child Jesus and the night.

5. *Night as Bogy.* In Upper Brittany night appears as a bogy to scare children with: "Go home! Night will run off with you! Night's coming after you." At Matignon (Côtes-du-Nord) night appears as a great black woman, who lives in the west, between earth and sky, and frightens children who do not get home at the proper time. In Morbihan, when children do not want to go to bed, they are told that "Madame la Nuit" will come to take them. She is represented as a big black woman; and, when children will not let themselves be cleaned up, they are told that their face will be as black as that of Night. At Saint Brieue there was a "cave of Madame la Nuit," into which little boys furtively threw stones and then ran away. But, usually, mankind has relied upon darkness in general, in thought personifying it, as the "bug" with which to "fear boys." Sometimes, however, the night-bogy is a witch in animal shape (owl, vampire, dragon, wolf, etc.), or

some horrible ogre or misshapen being of human kind. Night, as bogy, however, is not always conceived of as a woman. In Scottish folk-lore we find "Auld Daddy Darkness," who is "black as a blackamoor, blin' as a mole."

6. *Night and Marriage.* The consummation of marriage in the hours of darkness is a practically universal custom among the races of man, though there are still some exceptions and there have been, doubtless, more in times past. In spite of the proverb "happy is the bride on whom the sun shines," and the efforts of ecclesiastical authorities at various periods to confine the marriage ceremony to morning, high noon, etc. (in the sixteenth century we find unscrupulous priests rebuked for uniting couples in "the night season," or "by the light of the moon"), a large proportion of weddings take place in the evening, the hospitality of that portion of the twenty-four hours adding naturally to the festivities and rounding out the ceremonies in various ways. The Church of England law (4 Geo. IV, c. 76) required that all marriages must be celebrated between the hours of eight and twelve in the morning," but this was latterly changed (49 and 50 Vict., c. 14) to between the hours of eight in the forenoon and three in the afternoon. The fashion of "wedding-journeys" also favored day-marriages, until the appearance of sleeping-cars and steamboats with "staterooms" tended to turn the tide somewhat the other way. Among many more or less primitive peoples (Santhals, Maoris, Babar Islanders, etc.), and some partly civilized, the marriage ceremony takes place in the evening or at night. With the ancient Romans the bridegroom had to go to his bride in the dark, and in Sparta he had to leave her before daybreak, so that "sometimes children were born before the pair had ever seen each other's faces by day." This surreptitious exercise of conjugal duties by the bridegroom at night is found here and there all over the globe, where darkness is thought to be the proper veil for these events, and where men seek to avoid the dangers lurking in the "contagion of sight." Sometimes both bride and groom are secluded for days, *e. g.*, among the Minahassas of Celebes, they are shut up in a dark room for three days and nights, and elsewhere often for a much longer period. The taboo against seeing the fairy bride "by candle-light" appears in certain folk-tales.

Crawley, who has paid much attention to the study of human taboos, prohibitions and devices for the avoidance of danger, particularly in the congress of the sexes, remarks: "Weddings very commonly take place in the evening, or at night, a custom natural enough for its convenience and its obviation of dangers, such as that of the evil eye and those connected with human, and especially with female, shyness and timidity." To this

he adds significantly: "Taken in connection with the last custom [greeting of the rising sun by the young pair], we may, without excess of fancifulness, note the coincidence with nature's method of shrouding her processes of production in mystery and darkness, and of revealing their results in the light." Behind the bridal veil and other means of concealing the woman in part or altogether from her husband, etc., lies a wealth of folk-lore. Hiding the bride, or keeping her in a dark corner, figures in many wedding ceremonies, and when real darkness is not present, fictitious night is called into play.

When the "daughters of the gods" have to do with the "sons of men," or these with the former, it is often only by night that they can meet each other. It was thus in the Maori legend of the hero Tawhaki and the celestial maiden Tango-tango, who fell in love with him, and nightly came to him, stealing home with the advent of dawn. There are many variants of this tale among the Maoris and elsewhere in the world of savagery and barbarism, not to speak of more civilized peoples. The "heavenly bride," "the ghost wife," "the fairy mistress" are all often but nocturnal visitants, compelled to return to their superhuman dwellings at the first peep of day or at the stroke of midnight. Often, too, the child of "the walker by moonlight" has to be suckled or saved from some great danger by its "uncanny" mother, whose power to aid it lies wholly within the hours of darkness, or is even confined to midnight alone,—at which time only, *e. g.*, "the lady of the lake," in response to the child's cry and the nurse's appeal (as in a Kaffir tale) rises out of the water and puts it to her breast.

7. "*Fair by night and foul by day.*" One of the most noteworthy motives in popular legend and fairy-tale is that of the wife or husband who is "fair by night and foul by day,"—a beautiful human being during the hours of darkness, but a serpent, a dragon, or some other ugly or loathsome creature, if not a hideous man or woman, after dawn. The typical case in literature is "the foul old wife," who figures in Chaucer's "The Wife of Bath's Tale." This famous story and its numerous analogues in other languages than English have recently been studied by Prof. G. H. Maynadier. In Chaucer the knight, who has married the old wife ("a fouler wight there may no man devise"), is told: "Choose, now, to have me foul and old and a humble wife till I die, or young and fair, and take your chances of my lovers." When he told her to please herself, the old hag became "as true a wife as ever was, and fair as any lady or queen in the whole land," and they lived happily ever afterwards. In the ballad of *The Marriage of Sir Gawaine* (ante Charles I), "the lady gives Gawaine his choice

to have her fair by night and foul by day, or *vice versa*." The knight leaves the matter to her and she then declares that she will be fair always,—she had really been bewitched by her stepmother. In the Saga of Hrólf Kraki (14th century) it is told of King Helgí that one night "a wretched female shape" sought entrance to his hut and bed. The king admitted her, but lay all night with face averted from her ugliness. But, "when at daybreak he looked round, a creature of surpassing beauty lay by him, who at once began to fill him with love." This boon of a prince's bed was the ending of her enchantment, for she, too, had been bewitched by a cruel step-parent. In many tales and legends in which the "fair-foul" motif is employed the maiden or youth is awakened from an enchanted sleep or restored to a fair human from a foul bestial shape by the kiss of a lover hero or heroine. Often the "loathly lady" was a good fairy, as Maynadier suggests, who was not under spells at all, but was merely wishing to test her favorite hero. To such a motif various clumsy additions may from time to time have been made. Among the changes of form from night to day cited by Maynadier from the folk-literature of all lands are the following:

1. A prince by night, gray bear by day (Celtic).
2. Gray wolf by day, gentleman by night.
3. Maiden by day, serpent by night,—recovers for good her human form after a third kiss (Rhaeto-Romanian).
4. Prince by night (*i. e.* after sunset), frog by day (Breton).
5. Boy by day, werwolf by night (Breton).
6. Man by day, bear by night (Scandinavian).
7. Man by night, white bear by day (Scandinavian).
8. Prince by night, lion by day (German).
9. Prince by night, crab by day. Also alternately man and eagle (Greek).
10. Young man by night, pumpkin by day (Wallachian).
11. Prince crane by day, man by night (Scandinavian).
12. Man by day, worm by night (Scandinavian).
13. Man by night and hoodie by day, or *vice versa* (Scotch Highland).
14. Man by night and white dog by day, or *vice versa* (Irish).
15. Man by day, seal by night (Irish).
16. Man by night, ram, salmon, eagle by day (Irish).
17. Princess by night, swan by day (Irish).
18. Man by night, raven by day (Gascon).
19. Prince with monkey's head by day, handsome youth at night (Norman).
20. Princes swans except for a quarter of an hour every evening (German).
21. Women by night, stags by day (German).
22. Handsome youth by night, lizard by day.
23. Tree by day, beautiful youth by night (S. Amer. Ind.).
24. Princess a raven except for one hour each night (Armenian).
25. Man by night, snake by day (Servian).
26. Man by night, bird by day (Scotch).
27. Man by night, ring by day (German and Servian).

A story of the rattlesnake (by day) youth (by night) kind has recently been reported from the Tunika Indians by Swanton, and the myth is "of a common American type."

Sometimes, it will be readily seen, the human being appears in proper form by day, sometimes by night. How much of this motif of the alternation of the good and the bad, the beautiful and the ugly, the human and the infra-human (or ultra-human), is due to the contemplation of the natural alternation of day and night is difficult to determine. Doubtless, the metamorphosis of day and night had not a little to do with suggesting the changes of man into beast and *vice versa*.

8. "*Nightmare.*" The "nightmare has been a very fertile source of mythology and folk-lore. The "mare" in this word has, of course, nothing to do with *mare* (or *horse*), but is by folk-etymology so interpreted,—in Icelandic, *e. g.*, the cognate *mara* means an ogress. The Latin term for nightmare, *incubus*, from *incubare*, "to lie down upon," connotes the oppressive feeling about the chest, which is the starting point for the nightmare psychosis. With the modern peoples of Europe alone, leaving out of count altogether the uncivilized races of the globe, the lore of the "nightmare" and the "incubus" is very extensive. It was Laistner who first emphasized the *rôle* of the nightmare and the incubus, with dreams, in the production of mythologic phenomena and he was followed in this direction by Mogk, Meyer, Golther, etc.

Among the "swan-maiden" myths Hartland notes a "nightmare type." In the belief of many people in peasant Europe (Germany and the Slavonic countries), "the nightmare is a human being—frequently one whose love has been slighted, and who, in this shape, is enabled to approach the beloved object. It slips through the keyhole, or any other hole in a building, and presses its victim sometimes to death. But it can be caught by quickly stopping the hole through which it has entered." In folk-tales a man stops up the means of egress and suddenly finds in the room "a young, lovely maiden," whom he marries and by whom he has children. If questioned about her nightmare origin, or for other reasons, she sometimes vanishes after years of happy wedded life. Sometimes the nightmare, when caught in this way, turns out to be a beautiful child, who marries and, in like manner, disappears when the question of her origin is discussed. Often the nightmare slips out and in again if an opening is accidentally left. There are many curious folk-beliefs concerning these "nightmares." In North Germany, *e.g.*, "when seven boys, or seven girls, are born in succession, one of them is a nightmare." From the distressful *incubus* to the elusive beauty is a long step, but the folk-mind easily makes it.

9. *Night and work.* In a certain sense, night was the first *schola* or leisure of man, and long continued to be such. It was only with the advent of fire that night was permanently and successfully "tamed," industrialized and estheticized. The discovery of fire really genialized night for man, making possible many of the social arts, including letters, song, and music, to a large extent, at least. Even-songs, "night-thoughts," and "musings, while the fire burned," have added much to the stock of human knowledge.

Says Groos, with some exaggeration, perhaps: "Of children and young animals it is true that, except when they are eating, they play all day, till at night, tired out with play, they sink to sleep." This is before the school interferes with the natural activities of childhood, or social necessity makes them all too soon feel the burdens of labor. For the child, day-time is play-time, and night-time is rest, and both are, or should be, equally genial. Civilization, however, has long ruthlessly disturbed both by the evils of child-labor in the factory and the mine, from which, even now, children of both sexes still suffer much. The night-labor of children has not yet completely disappeared from the Old World or even the New. Those to whom night belongs of right have not all received it.

Woman is perhaps more night-minded than man. In another place the present writer has observed: "Traces of the night-inspiration, of the influence of the primitive fire group, abound in woman. Indeed, it may be said (the life of southern Europe and of American society to-day illustrates the point abundantly) that she is, in a sense, a 'night-being,' for the activity, physical and mental, of modern women (revealed *e. g.*, in the dance and the nocturnal intellectualities of society) in this direction is remarkable. Perhaps we may style a good deal of her ordinary day labor 'rest,' or the commonplaces and banalities of her existence, her evening and night life being the true genius-side of her activities." And "in acting and dancing [and we may perhaps add singing], two professions especially of the night, woman shows marked genius, exceeding even that of man." Recent years, however, have seen an extensive utilization of the afternoon for the meetings of woman's clubs, which now compete or coalesce with pink teas and like post-meridian functions.

The Masai of eastern Africa believe that the night is a man, whose wife is the day. They explain this by saying that "men, who are strong, go and fight the enemy at night, whilst women, who are weak, can only work by day." The amount of work done by women among many primitive, and even civilized, peoples, is so great that not a few writers would agree with the exaggerated statement of Gen. Dodge, cited by Prof. O. T.

Mason, that "it is a god-send that the Indian woman did not know how to make a light sufficient to work by at night." Then, surely, woman's work would never be "done."

But, although mankind have accomplished so much work at night. and the praise of the pioneer student who picked up his education by the uncertain light of the camp or cabin fire, is repeated on behalf of him who "burns the midnight oil," or keeps the electric lights going till long past that fateful hour, there is some evidence that the conquest of night achieved by civilization has not been equally powerful everywhere. The familiar gospel hymn with its refrain,

> "Work, for the night is coming,
> When man's work is o'er,"

goes back to the saying in the New Testament (John ix, 4), attributed to Jesus: "I must work the works of him that sent me, while it is day: the night cometh when no man can work." But, if no man can work in the night, the folk-lore of all lands represents Satan as losing no hour of darkness in his nefarious labors. Still the poets have emphasized the restful night, as *e. g.*, Montgomery, who begins his poem on night thus:

> Night is the time for rest;
> How sweet, when labors close,
> To gather round an aching breast
> The curtain of repose.

Before him, however, Watts had warned that "Satan finds some mischief still, for idle hands to do."

In certain parts of France the folk-belief obtains that working in the fields after nightfall is dangerous. If one does so, he risks coming into contact with headless men, sprites and demons of all sorts. In upper Brittany, if a man works in the fields at dark of night, the devil comes beside him and performs the same actions as he, and, if the laborer does not cease his work, carries him off. Sometimes, the spirits warn men who trespass upon the hours of night that are properly theirs. A legend from Ille-et-Vilaine states that a peasant, who was cutting grain at night, heard a voice call out to him twice: "You must leave the night to those to whom it belongs!" Another from the Ardennes reports that a giant said to those whom he found working at night in the forest: "The day is for you, the night is for me."

Recent studies of work and fatigue by the physiologists and psychologists have revealed the presence of at least two types of "workers" among scholars and men of various occupations and professions, the "night type" and the "day type," perhaps also a "morning type," and an "afternoon type." There are also not a few cases of individuals who get up at night to work,—

sometimes being at their best at two or three o'clock in the morning.

10. *Night and meals.* Even among civilized peoples, meal-times are by no means confined to the hours of daylight. Dinner, the chief meal, may take place at the noon hour or shortly after, at about six o'clock, or often much later in the evening. For social functions and kindred affairs eight o'clock is a common hour for dining. Supper, in England and France in the Middle Ages, and for three centuries after, was generally at about four or five in the afternoon. With regard to the Parisians, Mallery notes: "A substantive change even with them is the hour of the later meal (*i. e.* dinner), which is late in the evening, or in the night, instead of early in the afternoon, as it was a few generations ago." Here, as elsewhere, a shift from day to night has taken place. In our northern climate "lunch" at noon and "dinner" so late that artificial light has to be resorted to are quite fashionable, the night dinner in winter time being more characteristic by reason of the earlier oncoming of darkness. Add to this social affairs, church and theatre suppers, the "night lunch," etc., and it will be seen at once how large an amount of food civilized man is in the habit of consuming after daylight has practically disappeared. To the lamp have now succeeded gas and the electric light, making night activity in the matter of eating sociable and pleasurable to a degree. With primitive peoples the principal meal occurred very often (*e. g.* the Hupa Indians of California) in the evening, sometimes towards noon-day. But there were often other minor meals.

11. *Night and hospitality.* The necessity of asking for "a night's lodging" is one of the turning points in many a folk-tale and fairy story. That night should be the time for the exercise of hospitality is natural enough, since even now most of the moving about and travelling in the world are done by day. The ancient Hindus believed that "he who entertains guests for one night obtains earthly happiness; a second night gains the middle air; a third, heavenly bliss; a fourth, the world of unsurpassable bliss; many nights procure endless worlds." The duty and the exercise of hospitality were all the more necessary and serviceable since night was often the time when not alone the spirits of evil, but the souls of the departed and even the gods themselves walked the earth. If hospitality during the hours of daylight were commendable, it was doubly so after nightfall. At night, especially, did men feel the injunction of the primitive Ainu, "Do not treat strangers slightingly, for you never know whom you are entertaining," a thought which, in higher form, has found a place in our Bible, where we read (Hebrews xiii, 2): "Be not for-

getful to entertain strangers; for thereby some have entertained angels unawares." Night always has been, indeed, the time of "entertaining angels unawares." It is easier for all creatures to show their real colors by day. This very fact has tended to deepen the feeling of hospitality everywhere among men in all ages of the world's history. To keep any one "over night" is still the common expression of the art of hospitality. And often, since at night the whole family is present, the women in particular, hospitality has not infrequently gone to such extremes among uncivilized peoples in various parts of the globe that the *jus hospitis* has included the provision of a temporary consort or the assumption of conjugal rights over some female member of the household.

12. *Night as soother and counsellor.* In the New Testament (Ephes. iv, 26) we find this admonition: "Be ye angry and sin not: let not the sun go down upon your wrath." And nowadays people are sometimes told, when in a fit of anger, to "go out into the night and cool off." In poetic and in prose literature, as well as in folk-lore, the soothing effect of the "calm and silent" "peaceful," "quiet," "still," "tranquil," "solemn" night is emphasized. Night is, with sleep, the great cure for human ills; anger, worry, despair flee at her coming. As Ovid greatly phrases it: *Curarum maxima nutrix Nox.* Night hides defects that in daylight agitate the minds and souls of men. The French proverb has it, "by night all cats are gray," and the Greek, "when every candle is removed, every woman is alike."

In how many ways is not mankind, to use the Vergilian phrase, retouched by Conington, "released from trouble by the touch of night!" The French proverb, "Night brings counsel:" finds echoes in every land and in every age, from the German "counsel overnight is better," to the saying attributed to the Persians, "counsel must be taken twice; once by day, again at night."

Night and sorrow are easily and commonly associated. Said the English poet James Montgomery (1771-1854):

> "Night is the time to weep,
> To wet with unseen tears
> Those graves of memory where sleep
> The joys of other years."

and, both in literature and in folk-lore, we meet with this selection of night as the appropriate period for grief and its expression. The use of fire and its association with religious ceremonies doubtless made funerals and funeral rites during the hours of darkness possible to uncivilized man, and so, much of the ritual of death and of mourning was transferred to the night, when by the light of his own camp-fire, he started off

the dead on their long journey to the world beyond, whose lights he saw burning in the skies above him. And it is no wonder that the Australian aborigines, who conceive of the milky way as the path of souls, see in its stars the camp-fires kept going by faithful wives, who have preceded their husbands, to light them on their journey to the spirit-land. Through darkness into light passes the soul of man at death, as at birth he came forth out of darkness into light.

13. *Weather-lore of night.* In literature and the sayings of the folk are to be found not a few prognostications of the weather of the morrow from the aspect of the night. In one of his sonnets, Shakespeare develops a fine figure of speech from this source:

> "Do not drop in for an after-loss.
> Ah, do not, when my heart hath 'scap'd this sorrow,
> Come in the rearward of a conquer'd woe;
> *Give not a windy night a rainy morrow,*
> To linger out a purpos'd overthrow."

One of the weather sayings of the African Masai is this: If, when the sun rises, the heavens are red, it will rain; if, when the sun sets the sky is the color of blood, some warriers out riding have been successful. It is not a far cry from this to one of the most famous of weather-proverbs, thus stated in the New Testament (Matthew xvi, 2, 3): "When it is evening, ye say it will be fair weather, for the sky is red; and in the morning it will be foul weather to-day, for the sky is red and lowering."

This has its counterpart in the common English sayings:

> Evening red and morning gray
> Will set the traveller on his way;
> But evening gray and morning red
> Will bring down rain upon his head.

> If the sun in red should set,
> The next day surely will be wet;
> If the sun should set in gray,
> The next will be a rainy day.

> An evening red and a morning gray,
> Are sure signs of a fine day.

> Evening red and morning gray
> Two sure signs of one fine day.

> An evening gray and a morning red
> Will send the shepherd wet to bed.

> Red skies in the evening precede fine to-morrows.

And more to the same effect.

The "rainbow at night" is noted in our English folk-lore:

> Rainbow in the morning,
> Shepherds take warning;

Rainbow at night,
Shepherd's delight.

A rainbow in the morning
Is the shepherd's warning;
A rainbow in the night
Is the shepherd's delight.

Rainbow at night,
Sailors' delight;
Rainbow in morning,
Sailors' warning.

If there be a rainbow in the eve,
It will rain and leave;
But if there be a rainbow on the morrow,
It will neither lend nor borrow.

The rainbow proverb is also expressed in more scientific language as follows: "Rainbow in morning shows that shower is west of us and that we shall probably get it. Rainbow in the evening shows that shower is east of us and is passing off."

Some proverbs and sayings relating to the actions of animals at night as weather signs are:

1. Bats flying late in the evening indicate fair weather. Bats who speak flying tell of rain to-morrow.
2. When swallows in evenings fly high and chirp, fair weather follows; when low, rain follows.
3. If the cock goes crowing to bed,
   He 'll certainly rise with a watery head.
4. When grouse drum at night, Indians predict a deep fall of snow.

14. *Night as a measurer of time.* Among civilized peoples at the present time, as our common proverbs and sayings indicate (*e. g.* "every dog has his day"), measurement by day is so predominant that we have almost forgotten that our ancestors reckoned by night, that there was ever a time when not "in the days of——," but rather "in the nights of——" was the proper phrase; or, again, "Give us our *nightly*," not our "*daily* bread." As the moon was the measurer of longer periods of time, so the night was of shorter ones. The emphasis placed upon "night" is revealed by the fact that while, in the terms for "day" significant differences occur among the various Aryan languages, there is practical agreement in the words for *night* (a common Aryan stem *nokt* is recognized by philologists). This leads Kluge and others to argue that the primitive Aryans counted by "nights" and not by "days." Relics of such a procedure are to be found in our own English "sennight" and "fortnight," and in the German terms *Weihnachten* (lit. "holy night") and *Fastnacht*, etc. In the Rig-Veda occur such passages as this, which Schrader cites: "Let us celebrate the old nights (day) and the harvests (years)," and the Sanskrit *nicanicam* (literally "night for night") means "daily." Schrader thinks that in the oldest times the moon was the

measurer of time and day-reckonings only came into vogue with greater appreciation of the sun and the rise of a solar cult. Then, as the term *night* formerly included *day*, so the term *day* came later to include *night*.

The use of *eve* in English, *Abend* in German, in such ceremonial and holiday terms as New Year's Eve, Christmas Eve, Hallow e'en, St. Agnes Eve, Candelmas Eve, Easter Eve, St. Mark's Eve, etc., Christabend, Sonnabend, etc., to designate the "night before" a holiday or cult-period and sometimes even the day itself is worth noting.—*Sonnabend* means now all Saturday and not merely the part of it which just precedes Sunday; and *Weihnachten* includes likewise all of Christmas. And with the anniversaries of certain saints the "day" and "eve" are completely fused. In heathen times, before the word was consecrated to Christian uses, *Weihnachten* meant in German the "day before" the great winter festival celebrated from the 26th of December to the 6th of January, the "Yule" of older English. In reality, the old Germanic reckoning of time counted evening and night with the following day,—the diurnal period was from eve to eve, night being thus characteristically emphasized. From sunset to sunset has been a common method of computing the day of 24 hours, particularly for ecclesiastic purposes. The Hebrew Sabbath is of this nature, as was the "day" of the ancient Greeks. And in the story of creation in our Bible we read (Gen. i, 5): "And the evening and the morning were the first day." In older speech, as the German *Morgen* still indicates *morning* meant the early *morrow*. Both *night* and *morning* have thus at times signified the whole day, as *eve* and *morrow* have also been included in one complex. To count the "day" from sunset to sunset appears to have been a very common practice among the races of man (Hebrews, Greeks, Gauls, Teutons, etc.), and some have sought to bring it into relation with the moon-cult. The limits of "day" and "night" are often rather indefinite and peoples differ not a little as to their distinctions. In the Talmud-Mishna lore of the Hebrews this definition is found: "When the eastern sky becomes pale, it is twilight; when the eastern sky becomes so black that the upper and lower parts of the sky are of the same color, it is night." The "watches of the night," too, vary with different peoples. The Masai idea of night is thus reported by Hollis:

> The evening is the time when the cattle return to the kraals just before the sun sets (6 P. M.).
>
> There is also the time called nightfall, or the hour for gossip (8 P. M.); this is the hour before people go to bed.
>
> Then there is the night, midnight, and the time when the buffaloes go to drink—this latter is the hour before the sun rises, which the Swahili call *sava kumi* (4 A. M.).

There is also the time called the blood-red period, or when the sun decorates the sky; this is the hour when the first rays of the sun redden the heavens (6 A. M.).
Then there is the morning; this is after the sun has risen.

For the devil, who needs no sleep, the twenty-four hours, in folk-belief, often constitute two days, as his dupes in a compact with a time-limit discover to their sorrow. To the devil "nights are days," runs a French popular saying. A Picardy legend represents the devil as saying, when he came to demand the fulfillment of the pact earlier than his victim expected: "For us the day lasts from six in the morning to six in the evening; and from six in the evening to six in the morning is another day."

15. *Night vs. Day.* The opposition of day and night is a common feature of primitive mythologies. In Polynesia this opposition was highly systematized. On one side are the "dwellers in day," at the head of whom is Tangaloa, fair-haired and light-skinned, the beneficent god of daylight, inventor and promoter of the arts and activities of peace; on the other, Rongo, dark-haired and dark-skinned, the god of night and gloom, the stirrer-up and author of strife, bloodshed, war, and every form of discord and dissension. To one or other of these two classes belong all the gods. In several modern religions this same antagonism is reflected in the contest between the "God of Light" and the "Prince of Darkness,"—Christianity to-day has much of this belief still left in it. In the Middle Ages the idea was strongly entertained that Satan had vast power during the night, "until cock-crow," when God and his good angels regained their complete ascendency.

In many myths, particularly in some from the Indians of the northwest coast of North America, the occurrence of day is made possible by opening the box or other receptacle in which the light is confined, and letting it out. This feat, performed by cunning and stealth, is often one of the great achievements of the tribal heroes and demi-gods, *e. g.*, the raven, who figures prominently in this regard. Like the stealing of fire, the theft of light is a prime *motif* in every quarter of the globe. Sometimes sun, moon, stars, and light in general are separately or successively obtained for man from witches, demons, deities. And the myth of their origin is often very complicated. In some legends, the oncoming of day has a remarkable effect on the men of the primitive world. Thus, in a legend of the Tlingit Indians we read:

"When it became day and the men on earth saw each other, they all ran away from one another. Some turned into fish, others into bears and wolves, others again into birds. And in this manner arose all the various kinds of animals."

One would have expected such a result from the confusion of night rather than from the light of day. It suggests comparison with the actions of Adam and Eve after their obtaining the fruit of the tree of knowledge. But the "daze" of light is a common human experience, not unnoticed by the most primitive tribes of mankind.

Over against the miracle attributed in the Old Testament (Jos. x, 12-14), when "the sun stood still in the midst of heaven, and hasted not to go down about a whole day," and "the sun stood still, and the moon stayed, until the people had avenged themselves upon their enemies," may be placed the wonders reported at the funeral of St. Patrick, when, "for twelve days there was no night, no twilight, no darkness at all through the whole province; nay, for a whole year the nights were more luminous than usual and the clouds less heavy."

According to a myth of the Wiimbaio tribe of Australian aborigines, the sun never set at all in the beginning and it was light all the time. The people did not like this and so Nurali, a supernatural being, sang a song to this effect:

"Sun, sun, burn your wood, burn your interior substance, and go down!"

And so now the sun, after burning up his fuel during daytime, has to go far below the horizon to get more. Thus we have the alternation of day and night. Another Australian legend states that at night the sun, who is a woman, plunges into the earth, or into the water, to get lizards, roots, or fish, for she is hungry. In yet another, the sun is a traveller, who comes and goes. Other similar legends are found scattered all over the globe, among peoples of human races.

16. *Alternation of night and day.* The present alternation of night and day is not, according to many savage and barbarous peoples, the original state of affairs. This is evident from a glance at numerous creation myths. In our Bible we find the creation story of the Hebrews, wherein it is stated:

"In the beginning God created the heaven and the earth. And the earth was without form and void; and darkness was upon the face of the deep. And the spirit of God moved upon the face of the waters. And God said, let there be light; and there was light. And God saw the light, that it was good; and God divided the light from the darkness. And God called the light day, and the darkness he called night. And the evening and the morning were the first day."

Here we have the creation of light out of darkness by divine fiat, a procedure met with in ruder form in the creation legends of peoples all over the globe. This process is, however, entirely different from that appearing in many mythologies, where the question to be settled is often whether there shall be

eternal darkness or unending day. Sometimes one set of gods desires the former and another the latter, and a compromise has to be effected, resulting in the present alternation of daylight and dark.

That the alternation of night and day should be connected with gambling is natural enough. In the great gambling myth of the Navaho Indians, the action begins with an original alternation of day and night as we now have it, which was not satisfactory to all creatures dwelling upon earth:

"In the ancient days, there were, as there are now, some animals who saw better, and were altogether happier in the darkness than in the light; and there were others who liked not the darkness and were happy only in the light of day. The animals of the night wished it would remain dark forever, and the animals of the day wished that the sun would shine forever. At last they met in council in the twilight to talk the matter over, and the council resolved that they should play a game of hiding a stone in a moccasin (as in the game now called *Kesitce*) to settle their differences. If the night animals won, the sun should never rise again; if the day animals succeeded, never more should it set. So, when night fell, they lit a fire and commenced the game."

In this game some of the gods joined with the animals of one side or the other, whispering secrets, giving advice, etc. The night animals were helped by "the great destroyer," Yeitso, the day animals by the wind-gods. The coyote was too cunning to declare absolutely for either side, and so "he usually stood between the contending parties, but occasionally went over to one side or the other as the tide of fortune seemed to turn." The game was long and the streaks of dawn appeared on the horizon before it could be finished. The animals broke up the play in confusion, each hastening home as fast as he could. And, the tale concludes: "As the animals never met again to play for the same stakes, the original alternation of day and night has never been changed."

17. *Night and literature, art, etc.* It is not by accident that the best known collection of stories from the Orient bears the title of the "Arabian Nights." This reminds us of the fact that night (or evening) is the time *par excellence* for tale-telling all over the globe,—the camp-fire and the story still belong together, as they have done from the beginnings of human history. In the cold north the long winter evenings, and in the warm south the beautiful starry skies of night, created and sustained literature. The suggestive power of night has been infinite,—darkness, moon and stars, quiet, noise, etc., all have had here their influence. Night is poetic and mythopoeic. The poet has well said:

"Night hath made many bards; she is so lovely.
For it is beauty maketh poesie,
As from the dancing eye come tears of light.
Night hath made many bards; she is so lovely.
And they have praised her to her starry face
So long that she has blushed and left them, often."

But the ugliness of night, no less than its beauty, has been stimulating. This appears from hundreds of myths and legends in every part of the habitable earth that tell of what has been

"Swallowed up and lost
In the wide womb of uncreated night."

But the "lone watcher of the skies" has perhaps given mankind more of good than of evil, more of pleasure than of pain, from his inspirations. And it was to "the shepherds watching their flocks by night" that the angels on high sang the song to whose music the whole world shall some day move. Man, stimulated to song by the aspect of the nightly heavens, attributes to the cosmos his own feelings and emotions, and hears "the music of the spheres," begun when "the morning stars sang together, and all the sons of God shouted for joy." It is not surprising, therefore, that among some more or less primitive peoples tale-telling in the daytime should be tabooed, and music and the dance confined almost to night alone. Fire stimulated to an unwonted degree the activities of man at night and "tamed" the hours of darkness for the service of man, a service which the discovery and extended employment of the torch, gas, and electricity have now made practically universal.

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SOME ASPECTS OF MEMORY IN THE INSANE [1]

By FLORENCE BERENICE BARNES

Report of Experiments Performed in the Psychopathic Ward of the University of Michigan

The object of the experiments was to repeat on the insane certain of the experiments that have been used with normal individuals in the endeavor to understand in more detail the changes of memory in insanity. Our particular problem was to determine the rate of learning and degree of retention as compared with the normal and to study the relative value of 'heaped up' vs. divided repetitions and the influence of generative, effectual and retroactive (Rückwirkende) inhibition.

In the experiment the learning method and the Treffer method were used in approximately the pure form.[2] In the learning method, it will be remembered, impression is measured by the number of repetitions needed for the first perfect repetition, and the degree of retention by the number of additional repetitions required after the lapse of a given time to bring the series back to one perfect repetition. In the Treffer method impression is measured in the same way, but retention is tested by the number of cases in which the second syllable in a pair can be supplied when the first is suggested. Ordinarily the syllables are given successively and paired by accenting every other syllable. In addition in our work the syllables were paired by writing two syllables side by side on the cards. In the experiments by both methods both the one column and two column cards were used. The one is referred to in the text as the learning or reading syllables in single order, the other as learning or reading in double order.

It may be interesting to note that it is much more difficult to make out lists of nonsense syllables in English than in German, for the English language has a large number of words of three letters while the German has comparatively few. The number of nonsense syllables left after striking out those that make sense from the combinations of letters is correspondingly small. Our diphthongs, too, are less numerous than the German diphthongs and umlauts, and diphthongs in our experiments were found to confuse the subjects to a very marked degree.

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[1] Communicated by W. B. Pillsbury.

[2] Ebbinghaus: Grundzüge d. Psychologie, 2 Aufl. p. 646 ff.

It was found possible to perform the whole series of experiments with but two subjects, patients suffering from syphilis of the brain with mental disturbances. These patients were subject to convulsions every few weeks and would have no memory after the attack of what had occurred to them during the attack. In fact, they knew that they had been ill only by the feeling of dizziness and weakness, and the general soreness that resulted from the convulsions. Both subjects were easily fatigued, and after a very short time of testing would complain of dizziness and the complete vanishing of the impressions from mind when the card was removed. In addition to these two patients a number of others were used for one or more problems. A number of forms of mental disease were represented in the different experiments. The others could not be counted on regularly, however, as they are often incapable of learning a series completely, no matter how great the number of repetitions, and in the circular cases there would frequently be days when the patient would be incapable of working. The tables will indicate the forms of insanity to which the patients were subject.

Certain general difficulties in the conduct of experiments upon the insane may be noted in advance in connection with the departure from the ordinary course of procedure that they necessitate. The conditions of the subjects vary not merely from day to day, owing to the stage of excitement or depression in which the subject is found, but they vary from moment to moment. Nearly all cases are very much given to introspection. They are constantly thinking of their own condition and one can never say when the learning will be interrupted by some impelling thought of themselves. This may be suggested by the syllables, or by some chance incident, internal or external. Coupled with this attention is easily distracted, and will seldom be given long to one subject or task. It was this that compelled the use of the *Treffer* method. For in the method of learning repeated mind wanderings might prevent the learning entirely, a series might never be repeated a sufficient number of times, without distraction, to permit it to be learned, and so no test would be possible, while it would be possible to get a sufficient number of repetitions to forge some links, and these could be tested at favorable moments. By the *Treffer* method the strength of each link of the chain may be tested, while in the learning method the strength of the chain as a whole alone can be taken into account, and the strength of the chain is the strength of the weakest link.

This consideration, too, dictated making the apparatus as simple as possible, so that all elaborate exposure or recording apparatus was done away with and the syllables printed upon

a card and all exposed at once by passing the card to the patient with the request to commit to memory. This method of course brought in disturbing inhibitions but it obviated the necessity of teaching the patient to shuffle the cards at regular intervals, and insured that none should be omitted, through the patient's clumsiness of manipulation.

The first two part problems that we have dealt with are the influence of the different repetitions, and of the number of syllables in a series upon the formation of association. Ebbinghaus[1] found for normal individuals that the repetitions were all of equal value. In the insane this is not at all the case. The first repetition is of much greater value than any of the others. The next eleven repetitions hardly double the number of right responses by the Treffer method. The explanation is to be found in fatigue and wandering attention. In this connection it may be remarked that in the insane much more even than in the normal, failure to learn is due to failure to attend. The number of repetitions is much less important than the character of the repetitions. Attention affects both the strength of the associations and the strength of the perseverance tendency, and upon these two factors alone depends the liability to recall.

As far as fatigue does not enter, we might suppose that the same number of repetitions of a series of syllables would bring the same strength of syllable associations, no matter how long the series is. But many accidental influences may enter to add to or detract from certain associations, and the longer the series is, the more chance they have to act. The same number of readings of a series fatigues according to the length of the series. This results in paying less attention to the last readings than to the first. The longer the series, the more numerous the syllables in readiness to rise to consciousness, and so the number of inhibitions proceeding from them is greater, and a greater number of readings is necessary to learn them.

The first and the last syllables of a series make a stronger impression than those intervening, though sometimes the first syllable, instead of calling more forcible attention to itself simply draws forth attention which is directed on to the second and following. The degree of stress also strengthens the syllable by setting up certain kinæsthetic associations of the tongue and palate.

In Table 1 is given the number of repetitions necessary to learn series containing different numbers of syllables from six to twelve. It will be recalled that with normal individuals six to eight syllables can be learned at one repetition, twelve in fourteen to sixteen repetitions. The disparity against the in-

[1]Ebbinghaus: Ueber das Gedächtniss, § 19.

sane is increased by the fact that not more than twelve repetitions could be made on the same day without unduly fatiguing the patient, and this must of course be rigorously avoided. In accordance with Jost's law this should greatly reduce the number of repetitions required.[2]

TABLE I

Subjects.	Syllables.	Repetitions.	Subjects.	Syllables.	Repetitions
F—	6	14	S—	6	Infinite.
	8	25	Manic	8	"
Cerebral	10	41	Depressive	10	"
Syphilis	12	49	Excitem't	12	"
B—	6	12	S—Manic	6	"
	8	16	Depressive	8	"
Cerebral	10	37	Depres'ion	10	"
Syphilis	12	48		12	"
R—	6	8	R—	6	3
Paranoid	8	13	Maniacal	8	7
Dementia	10	17	Excitem't	10	11
	12	33	Nearly Recovered	12	14
L—	6	12	S—	6	2
Senile	8	17	Dementia	8	5
Dementia	10	too fatig'ing	Praecox	10	9
	12	" "		12	12

Note that the manic-depressives were unable to make any progress whatever in correctly recalling their series. This was due almost entirely to default of fixation, as before stated. The case of dementia præcox shows little defect of memory.

In the case of brain syphilis, perhaps, a few quotations from the patients' own remarks may serve to clear up these results more than any technical explanation.

"When I try so hard to retain them it increases the pain in my back and it shoots up into my head and makes me dizzy, and when I don't try hard to retain them they all leave me. Sometimes they go so I can't think or get them back at all, and sometimes I imagine I can see them and spell them. When I get lots of words, I get the words on different cards mixed up. Other ideas seldom enter—at least not so much now as they did." [Yet at the slightest interval of rest, patient will begin to talk of her home, her family, her condition, etc.] "The chief interruption has been the pain spells. With the dizziness, the syllables seem to vanish from mind. I think

[1] Jost: Zeitschr. f. Psych. u. Phys. d. Sinnesorg. XIV, p. 436.

of the syllables between times. In the morning when I wake up, I think of the words on the cards and try to repeat them all. I sometimes dream of them. The syllables seem to drop away suddenly and leave an absolute blank."

Inhibitions

There are a number of factors in the nature of the test itself, which hinder or inhibit the rise of the right response to consciousness, or tend to put another in its place. Two kinds of inhibitions noted by Müller and Pilzecker[1] are the generative and the effectual. Syllables already associated with other syllables are with difficulty associated with new ones. This is called generative inhibition. Effectual inhibition is caused by the mutual interference of the tendencies to reproduce each of two syllables which are associated with the one given. These two inhibitions commonly work together and are really two sides of one and the same process.

The test for noting the number and form of these inhibitions was given in the following manner. Two lists of syllables were made out thus:

1) v_1 u | h_1 u | v_2 u | h_2 u |
2) v_3 u | h_2 u | v_4 u | h_1 u |

Let v_1, v_2, v_2, v_4, represent different syllables; h_1, h_2 are respectively the same for each list; u differs in each case.

For instance,

(v_1) poli — (u) sil	(v_3 mag — (u) rit
(h_1) *tim* — (u) laim	(h_2) *lis* — (u) wef
(v_2)cholg — (u) bol	(v_4) paon — (u) loip
(h_2) *lis* — (u) fey	(h_1) *tim* — (u) neap

The two lists were written consecutively on the same card, as given, so that in reading the total number, h_1 and h_2, would be read in connection with two separate syllables each, and the two associations thus set up would be mutually inhibitive.

We will call h_1 and h_2 the chief syllables, since it is most largely with them that we have to do at present, and v_1, v_2, v_3, v_4 the stimuli, and u, in its various forms, the response.

It may be noted that in reading the second part of the list, the chief syllables already met in the first part, have become more or less familiar through this fact, and so tend to draw special attention to themselves, thus lessening the inhibition. Reading the chief syllables of the second part may also recall the syllables associated with them in the first part, and thus strengthen the associations. When both the associations are

[1] Müller und Pilzecker: Exper. Beitr. zur Lehre vom Gedächtniss. Zeitschr. f. Psych., Ergänzungsband I, pp. 144-168.

given in response to the chief syllable stimulus, we call it a double case. These double cases are of two kinds, according to whether the response of the first part or the response of the second part is given.

The lists are read in the same order at each sitting, but the stimuli are given in a different order each time, that they may be mixed up as much as possible, thus avoiding the elimination of inhibition by rote learning, due for the most part to a sense of the absolute position of the syllable in the series.

A little further explanation of the character of these inhibitions may help to an understanding of the results.

If a syllable h_1 already associated with u, is read in the new combination h_1 u_1 in general a re-arousal of the association h_1 u takes place, in that through the reading of h_1 the syllable u is placed in readiness, or in case the arousal is more intense, even brought into consciousness. This also has the effect, that the association h_1 u, through this re-arousal, gains in strength, or that at least an easier and quicker reproducibility exists for the next time. The intensity of the associative re-arousal depends on the strength which the association h_1 u possesses at the time of giving the combination h_1 u_1. This is dependent on the amount of attention given to the combination h_1 u when it entered consciousness, on the number of repetitions which it received, and on the length of time which separated the reading of the combination h_1 u_1 from that of the combination h_1 u. If by reading the combination h_1 u_1 the earlier formed association h_1 u is aroused, this associative re-arousal has not merely an intensifying effect for the association h_1 u or at least the reproducibility of u, but it acts at the same time as an inhibition for the forming of the association h_1 u_1. This generative inhibition not only takes place when in the reading of the combination h_1 u_1 the syllable u always comes into consciousness after the appearance of h_1 but also when at the appearance of h_1 the syllable u is placed in readiness, and in reality only a recognition of h_1 takes place. The more intense the re-arousal of the combination h_1 u by the reading of the combination h_1 u_1 the stronger is the generative inhibition for the association h_1 u. These inhibitions may not take place in cases of flights of association, since the combination h_1 u may not be strongly enough associated to inhibit the association of h_1 u_1 but in these cases the latter association, weakened by the same cause, is not strong enough to be recalled when the stimulus is given. As a rule, an impulse from a nerve centre along two courses will take the course which has been most frequently travelled, but if obstructed in any way on this course, will turn all the more strongly into the new path. Results of these two forms of inhibition are given in Table II.

TABLE II

Subjects.	Number of Tests.	No. of Inhibitions.	Double Cases.
B— Cerebral Syphilis	8 (1st series in dif. orders.)	6	2
	8 (2nd series in dif. orders.)	4	4
	8 (3rd series in dif. orders.)	5	3
Total	24	15	9
F— Cerebral Syphilis	8 (1st series in dif. orders.)	7	1
	8 (2nd series in dif. orders.)	5	3
	8 (3rd series in dif. orders.)	5	3
Total	24	17	7

In the manic depressives it was impossible to obtain results in these tests. During excitement the number of random associative combinations with syllables of the series being given, or with some other was so great that the strength, or even the existence of inhibitions could in no way be accurately determined, while in depression one cannot tell whether the customary unresponsive attitude of the patient to the stimuli is due to specific inhibition of any particular association or to the general associative retardation peculiar to this state.

These tests were rather too difficult to be applied to the patients afflicted with other forms of insanity mentioned in the results of the simple repetition tests.

From the results given in the tests of the two cases of cerebral syphilis, we see that although a supposed disintegration of the centres has here taken place, thus increasing the difficulty of forming associations, yet when once formed they may have an inhibitive influence on the formation of new ones. It is to be noted, however, that the inhibitions in these cases were for the most part negative rather than positive, that is, it would most often be found impossible to give any response to the stimuli with double combinations, rather than that the syllable combined with one should be given as a response to the other. This shows that the inhibition in these cases is due, not so much to the influence of a definitely formed previous association as to a generally confused and retarded mental state incident to the disease.

Closely related to these inhibitions is the "rückwirkende" or

retroactive inhibition.[1] In the reading of a syllable series certain physiological processes, which serve to strengthen the associations set up by the reading of the series, last a certain time, with gradually decreasing strength. These processes, and their beneficial influences on the associations are more or less weakened, if the person experiences an interval of mental activity immediately after the reading of the series. This mental activity, creating new associations, tends to weaken the old ones,—thus inhibiting their retention and recall,—just as established old ones hinder the formation of the new.

This inhibition is naturally stronger, the greater the attention given to the following mental activity, and the earlier it takes place, so that a period of rest between the readings is advisable if this is to be eliminated. (See discussion of Jost's Law.) Not only mental activity in the form of work results in this inhibiting tendency, but every strong distraction of the attention immediately after the impression of an idea injures its retention. Impressions should have time to *set* or *consolidate*. This is especially important in testing pathological cases, since frequently, though the series is read with seemingly good attention, immediately after reading the subject may be attracted toward or remark about something in the room, or pertaining to his own condition or affairs.

The retroactive inhibition was found to have much greater influence in cases of associative incapacity than in the normal, because the previously formed associations have so little strength that any different activity immediately following their presentation becomes a serious obstacle in the way of their retention. The tests for observing this inhibition particularly were made in three ways: 1, the subject was required to read a series of syllables of the same length as the presentation series, immediately after the reading of the latter. He was then required to recall as many as possible of the presentation series; 2, a piece of poetry or a short newspaper article was read to the subject after he had finished reading the presentation series; 3, the subject was engaged in conversation for a few minutes after reading the series, without his knowing that it was done for a purpose. For instance, his attention would be drawn to something outside the window, or an interesting bit of news would be told him, or rather her, for the subjects were women.

The stimuli consisted of a simple series of eight syllables, and it was found necessary in all cases to have ten repeated readings with two minute rests between, before the interval of different mental activity following, since it will be seen by reference to Table I, that about twenty repetitions are required to learn an

[1] Müller und Pilzecker: *op. cit.*, pp. 174-198.

eight syllable series perfectly. In the results, the number of false and negative responses divided by two will give approximately the number of cases due to the retroactive inhibition. It was impossible to give twenty readings during a single test, as the element of fatigue, and resultant inattention would have destroyed the value of the results.

TABLE III

1. Reading of dif. series after presentation. (*10 series.*)

Subject.	No. Syls. Read.	Correct Recall.	False Cases.	Negative Cases.
F— Cerebral Syphilis	80	14	43	25
	Av. 8	1.4	4.3	2.5

6.8 ÷ 2 = 3.4 or 42% of responses influenced by inhibition. (10 series.)

Subject.	No. Syls. Read.	Correct Recall.	False Cases.	Negative Cases.
B— Cerebral Syphilis	80	17	49	14
	Av. 8	1.7	4.9	1.4

6.3 ÷ 2 = 3.15 or 39.3% of responses influenced by inhibition.

The large number of "false" cases in these results is due for the most part to associative combination of the syllables of the presentation series with those of the inhibitive series. The existence of this combination is none the less an inhibition to correct recall.

TABLE IV

2. Reading matter after presentation. (*10 series.*)

Subject.	No. Syls. Read.	Correct Recall.	False Cases.	Negative Cases.
F— Cerebral Syphilis	80	20	17	43
	Av. 8	2	1.7	4.3

6 ÷ 2 = 3 or 37.5% of responses influenced by inhibition. (10 series.)

Subject.	No. Syls. Read.	Correct Recall.	False Cases.	Negative Cases.
B— Cerebral Syphilis	80	25	22	33
	Av. 8	2.5	2.2	3.3

5.5 ÷ 2 = 2.75 or 34.4% of responses influenced by inhibition.

Notice the smaller number of false cases here, as compared with negative ones, as there is little chance for associative combination outside of the presentation series.

TABLE V

3. Conversation after presentation. (10 series.)

Subject.	No. Syls. Read.	Correct Recall.	False Cases.	Negative Cases.
F— Cerebral Syphilis	80	19	29	32
	Av. 8	1.9	2.9	3.2

6.1 ÷ 2 = 3.05 or 38.1% of responses influenced by inhibition. (10 series.)

Subject	No. Syls. Read.	Correct Recall.	False Cases.	Negative Cases.
B— Cerebral Syphilis	80	27	13	40
	Av. 8	2.7	1.3	4

5.3 ÷ 2 = 2.65 or 33.1% of responses influenced by inhibition.

If the results are closely examined, it will be seen that the inhibitive value is slightly greater than can be accurately determined, for the following reason. We have seen that an average of about twenty repetitions was necessary in these two cases to learn a given eight syllable series correctly. (See Table I.) We have also seen that the value of the individual repetitions decreases with their number. Therefore the first ten repetitions should give more than half correct results, merely because of the number of repetitions, so that the number of false or negative cases due to lack of repetition must be slightly less than half the total number, and those due to inhibition a little more than half, so that, on the whole, we may say that about forty per cent. of the responses in this test were influenced by retroactive inhibition from the various forms of mental activity following the readings of the presentation series.

ASSOCIATIVE COMBINATIONS

Probably the most fertile source of false cases is the tendency to combine elements of one association with those of another. There are two reproduction tendencies, one including the beginning and ending consonants, the other the vowels, and the most frequent combination is giving the consonants of one syllable and the vowels of another, viz.:—zet—kap—kep.

The response may be 1. a combination of the right syllable with the given stimulus; 2. a combination of the right syllable with a syllable following or preceding it in the series; 3. a combination of the right syllable with the syllable occupying the same absolute position in another series; 4. a combination of the right syllable with the syllable with which the stimulus is connected by association with a preceding or following syllable; 5. combination of right syllable with a once given false response to a given stimulus, or a similar syllable; 6. combination of right syllable with similarly stressed syllable in preceding group; 7. combination of right syllable with syllable of related series spelled backward; 8. combination with some word or sound of daily life not entering into the experiment.

To determine the number and character of associative combinations in the pathological cases under investigation, a test was given consisting of ten different series of eight syllables each; five of the series were simple lists, where the subject was required to recall as many as possible; and five were the double lists, where, after reading the series a certain number of times, the subject was required to state the syllable immediately following the chief syllable given as stimulus. With the exception of a case of maniacal excitement, the tendency to combination was greater in case of the former than of the latter, probably because in the latter each association is reinforced in a definite way by giving as stimulus the syllable directly combined with it in the reading. It is obviously extremely hard to classify each combination according to the eight divisions given above. It will suffice to say that one or more were found under each division, —enough to justify the classification which I have given. In the results, only those cases are noted in which the incorrectness was found to be really, or at least very presumably, due to associative combination. Each series was read ten times, both for the double and the single lists.

TABLE VI

Single Lists

Subjects.	No. of Syls.	False Cases.	Assoc. Combinations.
F—Cerebral Syphilis	40	25	19
B— " "	40	20	19
S—Maniacal Excitement	40	36	27

The correct and the negative responses are not listed, as they are of no value in this test. Note the great number of associative combinations in the case of maniacal excitement. These

belonged for the most part under classification 8, being often due to combinations with biblical names and references, having similar sounds. In the other two cases the combinations were for the most part traceable to classifications 3, 4 and 6, showing greater concentration of attention, inasmuch as the associations do not tend to wander outside of the work in hand.

TABLE VII

Double Lists

Subjects.	No. of Syls.	False Cases.	Assoc. Combinations.
F—Cerebral Syphilis	40	22	14
B— " "	40	19	12
S—Maniacal Excitement	40	36	29

In the last case a large percentage of the combinations were due to the sound of the stimulus given,—the tendency was to introduce the vowel of the stimulus between the consonants of the response. The person troubled with flight of association is easily influenced by similarity of sounds of words. This is perhaps seen more plainly in simple association tests, when he is required to tell what he thinks of when certain words are given as stimuli. In a large number of cases he will give a word rhyming with the one given or add a syllable to it to make a longer word. The percentage of false cases which are found to be associative combinations is little greater in case of the abnormal than of the normal. Of course the percentage of false cases is itself much greater than in the normal, so that the tendency to associative combination is also seen to be much greater, but in both normal and abnormal cases, false responses are largely due to this tendency to combine associations.

OTHER CAUSES OF FALSE CASES

A response is often given which is not a combination of the correct response with some other syllable,—but which has no elements of connection with it. This incorrect response may be due to one or more of several reproduction tendencies. The stressed beginning syllable of a group is connected with the unstressed end-syllable of the preceding group by an association of noticeable strength. Carrying this further, we may say that any syllable has a greater or less tendency to recall any preceding syllable of the series, according to the degree of stress of the syllable given, or those preceding. The same rule holds for the connection of a given syllable with those following it

in the series. This takes place through mediating associations of the intervening syllables.

Substitution is another important factor in false cases. For instance, if an idea *a* tends to reproduce idea *b*, an idea similar to *a* will also tend to reproduce *b*. This is active substitution. Passive substitution is the reproduction of an idea similar to *b*, on giving the stimulus *a*. Thus a syllable *a* may show a tendency to reproduce a syllable *c* which neither mediately nor immediately follows *a*, but only possesses the peculiarity of being associated with a syllable *b* which is itself associated with *a*.

Further causes of false cases, having close connection with the reproduction tendencies just mentioned, are the following:

1. Syllables given a week or a month before are recalled instead of the right one
2. When a given stimulus does not reproduce the right syllable it still brings it to the threshold of consciousness, so that it comes suddenly into consciousness and is named when the next syllable is shown.
3. In a few cases the response to a given stimulus is a stimulus that has already been given.
4. The given syllable may be one that will, together with the shown syllable, give the sound of a familiar word, viz., *bur—dok*.
5. Syllables similar in meaning to the proper one are sometimes given.

It may here be noted that ease of learning is increased in both abnormal and normal cases.

1. If two or more successive syllables have the same initial consonant.
2. If two successive syllables form a rhyme.
3. If two successive syllables contain the same vowel or diphthong.
4. If the final consonant of a syllable is the same as the initial consonant of the syllable immediately following.
5. If two or more syllables form a word or phrase, or if the syllable is itself a word.
6. Unusual combinations and those especially difficult to pronounce, are a hindrance to learning.
7. Rhythm is favorable.

Difference of Distribution (Jost's Law)

A period of rest of greater or less length between the repetitions of the syllable series has an important and favorable influence on their recall.

According to Jost, "Of two associations of the same strength but different age, the more recent disappears quicker than

the older,"[1]—so that the number of right cases is inclined to be less when the recall takes place immediately after the reading, than when a period of rest ensues, giving the impressions time to *set*, as it were. Jost found that the associations which were obtained by a constant number of repetitions of a syllable series possessed greater strength twenty-four hours after the last repetition, if the repetitions were distributed over several days, with intervals of twenty-four hours.

Jost also shows that the proved advantage of the distribution with long intervals cannot be wholly explained through the fatigue which is experienced from a greater number of repetitions immediately following each other, and as an explanation he formulates the important law that when associations are of like strength but different age, a new repetition possesses a greater strengthening power for the old association than for the new, or, in other words, associations of the same reproducibility disappear more slowly the older they are and the more frequently they are strengthened by new impressions.

It is a significant fact that the results show the influence of distributed repetitions to be markedly favorable in pathological cases, much more so than in the normal. This is due to the fact that the mentally defective subject is unable to keep his attention on the constantly repeated series until the time of recall, while the series whose repetitions are distributed over several days is met with fresh attention each day, and is reinforced in the interval by involuntary recall.

This test was conducted with the double series, each consisting of ten double, or twenty single syllables. One such list was repeated once a day for ten consecutive days. The other was repeated ten times daily until perfect recall was possible. Only one complete test could be made, owing to the difficulty of being able to arrange ten consecutive days on which the subjects were not kept from the experiments by their physical condition, as every care was taken that this work should not interfere in any way with the treatment and improvement of the patients. Owing to this many results had to be thrown out, because more than the twenty-four hours would intervene between experiments.

TABLE VIII

Subjects.	No. distrib. repets. nec. for correct recall.	No. consecutive rep ets. nec. for correct recall.
F—(Cerebral Syphilis)	10	40
B— "	10	40

[1] Jost: *op cit.*, p. 459.

As in all the tests, only ten consecutive readings were allowed daily, so that the results under this heading are diminished by the three twenty-four hour intervals necessary to forty repetitions.

One would conclude from the results of this test that persons with defective memories would find it very beneficial when memorizing, to distribute the repetition over as great a length of time as poosible.

Some results were taken to show the advantage of connected over disconnected matter in facility of learning, and the advantage of learning as a whole over that of learning in parts, but they are not sufficiently numerous or definite to offer very important explanations.

In conclusion, I desire to thank Dr. A. M. Barrett, Director of the ward, for permission to use the patients, for access to the case records and numerous suggestions in the course of the experiments.

SUMMARY

1. Increasing the number of syllables in a series increases the number of repetitions required in the case of these insane patients much faster than in the case of the normal individual.

2. Generative, effectual and retroactive inhibition are much more pronounced in their effect in the abnormal than in the normal.

3. There is much greater advantage in divided over 'heaped up' repetitions for the insane than the sane.

4. All the sources of confusion and error work more markedly for the pathological mind than for the healthy.

In short all the factors investigated are operative in the diseased as in the well mind, and with much greater force.

THE INTERMITTENCE OF MINIMAL VISUAL SENSATIONS

STUDIED FROM THE SIDE OF THE NEGATIVE AFTER-IMAGE

I

THE FLUCTUATION OF THE NEGATIVE AFTER-IMAGE

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I. Introduction

This paper is a continuation of a study published in this *Journal* in January, 1906.[1] In that article the fluctuation of minimal cutaneous and minimal visual stimuli was discussed. The absence of fluctuation for cutaneous stimuli was demonstrated by a series of experiments, upon a number of observers, with liminal pressure and electrical stimuli.[2] The fluctuation

[1] C. E. Ferree: An Experimental Examination of the Phenomena usually Attributed to Fluctuation of Attention: XVII, 81.

[2] This part of the work has recently been repeated and extended by L. R. Geissler (Fluctuations of Attention to Cutaneous Stimuli, this *Journal*, XVIII, 1907, 309), and the previous results are confirmed. On the score of method it may be noted that a very thin, narrow strip of high-grade wrapping foil does better service than Christmas tree foil, and that the tongue should not be protruded, but allowed to lie

of minimal visual stimuli was explained as a phenomenon of adaptation. The thesis was maintained, first that adaptation is rendered intermittent chiefly through the influence of involuntary eye-movement; and secondly that eye-movement interferes with adaptation in two ways: it reduces the time of stimulation, and by shifting the retina into a region of different stimulation, it causes the restoration of the adapted elements.

The first of the effects just mentioned is obvious; but the second demands explanation. That eye-movement does restore the adapted retina can, in the present state of our knowledge of the phenomenon, scarcely be questioned;[1] but why a single eye-movement, consuming but a fraction of a second, or even a group of eye-movements, is able to restore a color or brightness that required a much longer time for adaptation, is not readily understood and needs to be investigated. Both the fact and its explanation have been the subject of much discussion in the history of visual theories. This discussion will be touched upon only briefly. It is not our purpose here to give a detailed account of visual theories. That will be attempted in a later paper. The object at this time is briefly to state such phases of visual theory as will be sufficient to introduce our problem. We find, in general, two main types of theory: the one represented by Fechner,[2] Helmholtz,[3] Fick and Gürber, etc., called the theory of fatigue; and the other represented by Plateau,[4] Hering,[5] G. E. Müller,[6] and others, usually called the theory of antagonistic visual processes, or, when the after-effect of stimulation is more especially regarded, the oscillatory theory.

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naturally upon the floor of the slightly opened mouth, with its edges pressing lightly against the lower teeth and lip.

[1] See Fechner, Pogg. Ann., XLIV, 1838, 525; Helmholtz, Physiol. Optik, 1896, 510; Fick and Gürber, v. Graefe's Archiv, XXXVI, 2, 1890, 246; Hess, v. Graefe's Archiv, XL, 1, 1894, 274; MacDougall, Mind, XI, 1902, 316; XII, 1903, 289; C. E. Ferree, this *Journal*, XVII, 1906, 79-121.

[2] Pogg. Ann., XLIV, 1838, 221, 513; XLV, 1838, 227; L, 1840, 193, 427. The theory was conceived earlier by Scherffer (Abhandlung von den zufälligen Farben, Wien, 1765; also Journal de Physique de Rozier, XXVI, 175, 273), who explained the negative after-image by the diminished sensitivity of the fatigued retina.

[3] Müller's Archiv f. Anat. u. Physiol., 1852, 461; Pogg. Ann., LXXXVII, 45; Philos. Mag., (4) IV, 519; Physiol. Optik, 1896.

[4] Ann. de Chimie et de Phys., LIII, 1833, 386; LVII, 1835, 337; Pogg. Ann., XXXII, 1834, 543. More fully in Essai d'une théorie générale, etc., Mem. de l'Acad. de Belgique, VIII, 1834. For a still earlier form of the theory, see de Godart, Journal de Physique de Rozier, VIII, 1776, 1, 269.

[5] Zur Lehre vom Lichtsinne, 1874; v. Graefe's Archiv, XXXVII, 3, 1891, 1; XXXVIII, 2, 1892, 252.

[6] Zur Psychophysik der Gesichtsempfindungen, 1897 (off-printed from Zeitschrift f. Psychologie, X, 1896, 1, 321; XIV, 1897, 1, 161).

The oscillatory theory, in general, does not attribute to eye-movement any direct influence upon adaptation. As formulated by Plateau, 1833-35, it was primarily intended to explain the occurrence of the positive and negative after-images, the fluctuation of the negative after-image, and the flight of colors. Every light stimulation arouses two processes in the retina: the one corresponding to the positive visual impression, and the other to the negative after-image. When the eye has been stimulated by light and the stimulus is removed, the retina attains to its normal state only after a series of oscillations between these opposing processes. When the after-effect of stimulation is observed in an illuminated field of vision, the positive phases of the oscillating processes are obscured by the general illumination. Hence we have the phenomenon of the negative after-image and its fluctuation (the phases of invisibility of the negative after-image corresponding to the recurrence of the obscured positive after-image). When, however, the observation is made in a darkened field of vision, all the changes are noticeable. The changes thus observed in after-images of certain brightly luminous stimuli have been denominated the 'flight of colors.'

The phenomenon of adaptation was not discussed in this early form of the theory. It was taken into account only when the cardinal features of Plateau's theory (the antagonistic nature of the visual processes and the oscillatory after-effect of stimulation) were later made the basis of a group of visual theories, of which the Hering theory may be taken as the type. These theories were called upon to explain not only how the eye becomes adapted to a given stimulus, but also how, when once adapted, it is restored to its normal state. In general, they account for the restoration of the adapted retina by the conception of antagonistic processes; every visual process carries with it its corrective process. All factors extrinsic to the processes themselves are declared to be unimportant. It is said, *e. g.*, that the eye does not become permanently adapted to a given set of stimuli, or condition of illumination, first, because of the tendency toward correction inhering in the nature of the opposing processes, and, secondly, because the stimulation of the eye is continually changing, owing to changes in position of body and head, movement of eyes, blinking, etc. But these latter factors are on no account to be considered as exerting a direct influence on the retinal processes. They merely give the corrective tendency, inhering in the sets of processes, a better chance to operate.

It will be seen that the above mentioned provision explains the relief of adaptation only in a general way, and also inadequately. For, without taking into consideration extrinsic in-

fluences, it cannot account for the comparatively large measure of restoration brought about in the short intervals of relief from stimulation afforded by the involuntary eye-movements which occur under the conditions of normal fixation, or by voluntary eye-movements, of short duration, away from the stimulus and back again. The intervals are much too short for correction to take place, to such a degree, of its own accord.

As these disturbances in adaptation cannot be explained, they are denied to be of any considerable importance. Involuntary eye-movement under the conditions of normal fixation, or voluntary eye-movement away from the stimulus and back again, is said to exert no noticeable effect upon the restoration of the adapting stimulus, or upon its obverse aspect, the negative after-image.[1] The interval, during which the retina is shifted away from a given stimulus, must in point of time alone account for the progress it has made towards regaining its normal condition.

On the other side, however, the representatives of the theory of fatigue attribute a direct influence to eye-movement in restoring the stimulated retina to its normal state. This influence is inferred, more particularly, from the effect of eye-movement upon the negative after-image. The argument is as follows. A voluntary eye-movement, or a noticeable involuntary eye-movement, causes the after-image momentarily to disappear. The negative after-image may be taken as the index of retinal fatigue; hence whatever is able thus profoundly to disturb the cause of the after-image must also function in the recovery of the fatigued retina.[2]

According to Fechner (*opp. citt.*) eye-movement causes the after-image to disappear because of mechanical disturbances in vascular and nervous influences on the retina: temporary vascular congestion, etc. Helmholtz[3] says that eye-movement causes the after-image to disappear by producing changes in the illumination of the retina. Both writers, apparently, have practically disregarded the effect of eye-movement upon the total duration of the after-image; although, as will be shown later, this must be considered a much more important factor in a study of the restoration of the adapted retina than are the momentary disappearances or fluctuations of the after-image.

Of the more recent writers, Fick and Gürber contend that eye-movement changes the lymph-stream in a way that facilitates the removal of the fatigue products and the delivery of

[1] Hering: *opp. citt.*

[2] See especially Fick and Gürber, v. Graefe's Archiv, XXXVI, 2, 1890, 246.

[3] Physiol. Optik, 1896, 510.

new material to the fatigued areas. Hering,[1] replying to Fick and Gürber, denies to eye-movement any peculiar power to relieve adaptation. He asserts that movement of the field of vision, for example, answers the purpose equally well. Hess (*op. cit.*) contends that an adapted stimulus, steadily fixated, is not recovered, but does not explain how eye-movement restores the adapted retina. Finally, MacDougall (*opp. citt.*) explains the effect of eye-movement upon the reappearance of minimal visual stimuli on the basis of innervation.

This is the condition in which we find the problem at the present time. The oscillatory theory makes no provision for any noticeable effect of eye-movement upon adaptation, nor can it explain the after-image results which we ourselves have obtained. Fechner and Helmholtz aseribe to eye-movement a direct influence upon adaptation, but their hypothesis as to the way in which this effect is produced can be shown to be untenable. MacDougall's position has already been discussed by the writer;[2] while Hering, as will be shown later, did not carry his observations far enough.[3]

While, however, the literature does not furnish a satisfactory solution of the problem, it strongly suggests a method of investigation. It is evident that we cannot adequately study recovery while the stimulus is acting. We can only note the coincidence of eye-movement, or what not, with recovery. What goes on, in the small interval for recovery afforded by a single eye-movement, defies observation or experimental analysis. Fortunately, however, the after-effect of stimulation affords an easy and obvious point of attack. Here we can study recovery in isolation, and may hope to determine the factors that influence it: the factors that cause the fluctuations and affect the duration of the after-image. In accordance with this plan, a series of experiments on the negative after-image was begun in the Cornell University laboratory in the spring of 1904. The results of these experiments will form the subject-matter of this and the following papers.

The material may be classified under the following heads: I. Relation of the negative after-image to adaptation; II. Fluctuation of the negative after-image; III. Duration and fluctuation of the negative after-image with reference to its bearing upon the intermittence of minimal visual stimuli. This, the logical order of treatment will, however, be changed for the sake of convenience of discussion. The determination

[1] v. Graefe's Archiv, XXXVII, 3, 1891, 22.

[2] This *Journal*, XVII, 1906, 89.

[3] Fick and Gürber's hypothesis, although too indefinite and too speculative, seems to be the most promising of any of the historical hypotheses. It will be discussed later.

of the relation of the negative after-image to adaptation depends, in part, upon the results of the two succeeding inquiries, and can therefore be most conveniently taken up at the end of the series. We shall, accordingly, begin with a discussion of the cause of the fluctuation of the after-image, and of the factors influencing its duration. In terms of theory, these must constitute the factors that work for the restoration of the stimlated retina; for whatever theory is held of the adaptation and after-image phenomenon,—whether it be ascribed to fatigue, to antagonism of retinal processes, or what not,—the factors that work against the after-image operate to restore the stimulated retina to its normal condition. To make our position more secure, however, we shall report, in a second paper, adaptation experiments which show that the experimental variations that increase the frequency of fluctuation of the after-image and decrease its duration increase the time required for a stimulus to adapt; and, conversely, that the devices that decrease the frequency of fluctuation and increase the duration of the after-image increase the time required for a stimulus to adapt. The tests thus established will then be applied to the fluctuation of liminal stimuli. It will be shown that whatever increases the fluctuation of the after-image and decreases its duration, increases the phase of visibility and decreases the phase of invisibility of the liminal stimulus; and conversely, that whatever decreases the fluctuation of the after-image and increases its duration, decreases the phase of visibility and increases the phase of invisibility of the liminal stimulus; as should be the case, if the fluctuation of liminal stimuli is an adaptation phenomenon.[1] Thus the chain of identification will be rendered complete. The intermittence of minimal visual stimuli will have been made to answer to the tests for adaptation, from both its obverse and its reverse sides. Moreover, in the progress of the work. an answer will be found to the question how eye-movement is able to relieve adaptation.

The whole course of the work which we have undertaken on the fluctuation of minimal visual stimuli may be summarized as follows. First, an examination of the phenomenon was made for the ascertainment of its possible causal factors. These were found to be disturbances in accommodation; adaptation, which is found to be intermittent with normal fixation; fluctuation of attention; and physiological disturbances in the visual centre due to the function of other brain centres, such, for

[1] This result follows directly from the adaptation experiments just referred to. For whatever increases the fluctuation and decreases the duration of the negative after-image, increases the time required for a given stimulus to adapt (the phase of visibility when the stimulus is liminal), and so on.

example, as the respiratory and circulatory centres. Secondly, we eliminated, by experimental process, all of these factors with the exception of adaptation. Thirdly, we have been able to identify fluctuation with intermittent adaptation from both its obverse and its reverse sides. And fourthly, we have determined the factors that disturb adaptation.

II. The Fluctuation of the Negative After-Image.

There is a strong interest in the fluctuation of the negative after-image, independently of its bearing upon our special problem. It is generally recognized as one of the important problems in psychological optics, and one not as yet adequately taken into account by visual theories. We find, for example, Plateau, Aubert, Hering, Ebbinghaus and others holding that periodicity is grounded in the nature of the after-image process; the followers of Fechner and Helmholtz contending for accidental influences of various kinds which operate upon the fatigued retina; and Exner maintaining that eye-movement causes the after-image to disappear, because it distracts from clear perception. The question, then, is still open. The evidence is such that, unless prejudiced in favor of some particular explanation, one cannot subscribe to any without further investigation. Thus, von Kries, writing in 1905, testifies to the lack of decisive results as follows: "Die Frage, ob das Schwinden einer lokalen Umstimmung sich überhaupt in dieser Form eines allmählichen Abklingens vollziehe, ist (ohne messende Versuche) viel diskutiert und mehrfach in verschiedenem Sinne beantwortet worden." [1]

i. *Hering and Exner.*

In our consideration of the various theories, those which deny causal relation between eye-movement and fluctuation, Hering's and Exner's, will be examined first. The hypotheses which seek to explain the effect of eye-movement on fluctuation, Fechner's, Helmholtz' and Fick and Gürber's, will be deferred until a later point in the inquiry. It is convenient to begin with Hering.

a. Hering's discussion of the effect of eye-movement on the fluctuation of the negative after-image (1891) grew out of a controversy regarding the effect of eye-movement upon the restoration of the fatigued retina to its normal condition. In this discussion, he has not kept the two subjects formally separated, so that there must be more or less cross-reference between them in our review; although the centre of interest for us, at this stage, is the fluctuation of the negative after-image.

[1] Nagel: Handbuch d. Physiol. des Menschen, III, 216.

The whole question of the influence of eye-movement on the visual processes was raised by the representatives of the theory of fatigue. They sought to explain first why the eye, fatigued by a particular stimulus, recovers as quickly as it does; and, secondly, why it does not become progressively fatigued by light stimulation in general during the twelve hours or more of its exposure to light in the course of a day. The explanation was given chiefly in terms of the changes brought about in the fatigued retina by eye-movement. As has been stated above (p. 62), Fechner asserted that these changes are of the nature of mechanical disturbances in vascular and nervous influences; while Helmholtz attributed them to the more or less continual changes in the illumination of the retina due to eye-movement in connection with blinking, frowning, etc. Obviously, neither hypothesis is adequate to explain the facts in question.

Fick and Gürber (1890), taking up the problem at this point, were concerned first to furnish a more extended experimental demonstration of the fact that eye-movement is effective to relieve the fatigued retina; and secondly to explain, more adequately than had been done by Fechner and Helmholtz, how this relief is accomplished. The first point will not be discussed here. The explanation may be summarized as follows: eye-movement restores the fatigued retina by influencing the metabolic changes that take place in the fatigued area; it both facilitates the removal of the fatigue products from this area, and augments the delivery of new nutrient material to it.

Replying to Fick and Gürber, Hering denies that eye-movement affects the visual processes, and explains the absence of progressive fatigue by his conception of assimilative and dissimilative processes which are mutually corrective. He bases his denial that eye-movement is a factor in restoring the stimulated retina to its normal condition upon four experimental proofs, all adduced to show that it neither causes the negative after-image to disappear nor produces any other noticeable disturbance in its temporal course. These four proofs are as follows. (1) After continued fixation of a stimulus, the after-image does not disappear when the eyes are rapidly moved away from the stimulus and back again. (2) Movement of the background causes the after-image to disappear; hence eye-movement can possess no peculiar power to produce its disappearance. (3) Near-lying after-images due to successive stimulations do not fluctuate together. (4) Eye-movement does not cause the after-image to disappear, when it is observed in a darkened field of vision. These points will be taken up in the order given.

(1) The demonstration is as follows. If a disc or square of

dead black paper is laid on a white background, and its centre fixated for some time; and if the observer then moves his eyes quickly out to some near-lying point and back again to the neighborhood of the stimulus; the after-image is not found to have disappeared as a result of the movement.

Hering does not draw any specific conclusions from this experiment alone. It will be remembered, however, that by means of it and of the succeeding experiments he wishes to establish the thesis that eye-movement does not cause the disappearance of after-images, or otherwise noticeably interfere with their temporal course, and that it does not factor in the restoration of the fatigued retina. It seems fair to add, as an obvious corollary to this thesis, that it does not cause the fluctuation of the negative after-image. Now it is evident that the experiment is of little or no value in the present connection. (*a*) For to conclude from it that eye-movement does not cause after-images to disappear would be to generalize from a very special case, namely, from an after-image of high intensity. The result is very different when the after-image is weaker; eye-movement readily brings less intensive after-images to disappearance. In general, after-images obtained with so long or even with a less long period of stimulation must dim to some extent (the amount depending upon the time of stimulation) before eye-movement can cause them to disappear. (*b*) To conclude from it that eye-movement does not factor in the restoration of the fatigued retina to its normal condition would be to apply a test that is over-strict. It is not necessary that the after-image disappear. A dimming of the after-image should indicate partial restoration of the fatigued retina. In fact, the writer has shown in the rough, by a series of experiments to be described in a later paper, that the restoration of the adapted retina is proportional to the loss of intensity in the after-image. The disappearance of the after-image corresponds to complete restoration of the adapted retina, and should not be required as evidence that partial restoration has taken place. To demonstrate, then, that eye-movement factors in the restoration of the retina, it need be shown only that the after-image has lost in intensity; and proof of this is easy, however strong the stimulation. Observations made with reasonable care give the uniform result that after-images, of whatever intensity, are dimmed by eye-movement. (*c*) To conclude from it that eye-movement is not a causal factor in fluctuation would be to ignore certain relevant facts. After-images of such intensity do not fluctuate. Just as they must dim, to some degree, before voluntary eye-movement can cause their disappearance, so must they dim before fluctuation begins. If, therefore, the argument from

analogy is to be used at all, the investigator must first determine at what intensity after-images begin naturally to fluctuate, and at what intensity voluntary eye-movement of a suitable range begins to cause disappearance; and may then ask whether a rough correspondence obtains between the two points. This procedure was followed by the writer with a number of observers; and the results show, uniformly, an exceedingly close correspondence. A description of the method used and a statement of the results are given further on, p. 103 ff. Obviously, then, nothing can be derived from this experiment that will aid in demonstrating either the Hering thesis or its corollary.

(2) In his second observation, Hering is concerned to disprove Fick and Gürber's theory that eye-movement facilitates metabolic change in the retina. Even if disappearance does follow movement of the eyes, he says, it is not necessarily implied that eye-movement possesses any peculiar power to cause disappearance; for movement of the background yields the same result. The effect of moving the background is explained as follows: "Dies hat seinen Grund in der Wechselwirkung der Sehfeldstellen und zum Theile auch darin, dass die Augenmedien nicht ganz homogen sind und daher immer mehr oder weniger Licht von der Bahn abirrt, die wir ihm theoretisch zuschreiben." The explanation would seem to give up the whole controversy; for, as it stands, precisely the same effect should be produced by moving the eyes as by moving the background. However, we let this point pass, and proceed to consider the statement that movement of the background causes disappearance. That is true. It is possible, within limits, to duplicate, by movement of the background, any fluctuation series that may be produced by voluntary eye-movement. In all such cases, however, the eye is tempted to movement by the moving background. At any rate, when the eye is held steady, movement of the background does *not* cause the after-image to disappear. This may be demonstrated as follows. (*a*) Use for the background the mottled surface presented by the darker side of engine-gray cardboard. Project the after-image. Let it become sufficiently dim, and move the cardboard in any direction. Disappearance takes place. Now, place a fixation point immediately in front of the background; *e. g.*, a black knot in a taut vertical white cord. Fixate this steadily. Movement of the background scarcely dims the after-image. (*b*) The following method is probably not so fair a test of Hering's position as that just described, since he asserts that a change in the illumination of any part of the retina acts reciprocally on other parts. Hence the maximal effect would be produced, we may suppose, by movement of the whole background, and not by movement of the particular area

upon which the after-image is projected. However, the facts may speak for themselves. Use the same mottled engine-gray cardboard for the background. Place just in front of it a sheet of same kind of cardboard, with a hole of the exact size and shape of the after-image to be observed. Looking through this hole, project the after-image upon the background. Move this in any direction. Now that the major portion of the field of vision is steady. the shifting of the area upon which the after-image is projected does not noticeably disturb fixation, and correspondingly does not cause the after-image to disappear. (Instead of a sheet of cardboard, a disc mounted upon a color-mixer may be placed behind the opening. When the after-image is projected upon it, the disc may be rotated at any chosen rate of speed without sensibly dimming the image.)

(3) Hering's third demonstration is as follows. Place a short, broad strip of colored or dark paper on a white background 5 mm. to the left of a fixation point. Observe for 10 sec. Quickly remove it and place a similar strip, parallel to the position of the first, 5 mm. to the right of the fixation point. Observe for 10 sec. Remove this, and replace the first strip for 10 sec. Then remove the first, and replace the second strip for 10 sec. Thus the eyes have been exposed to both strips for 20 sec., with an intermission for each of 10 sec. The object of this arrangement was, apparently, twofold: first, by successive stimulation, to start the after-images in different phases of oscillation, and thus to cause them to fluctuate successively; and secondly, by causing them to fluctuate successively, to show that eye-movement cannot have been responsible for their fluctuation, but rather that oscillation is grounded in the nature of the visual processes. With regard to the first point, however, it can be shown that there is no especial virtue in successive stimulation to produce successive fluctuation in after-images situated on different parts of the retina. If two stimuli, not too large, are placed at a certain distance apart and allowed to act simultaneously, their after-images rarely fluctuate together. This is one of the common phenomena of fluctuation, whatever the temporal character of the stimulation, and it is in nowise essentially dependent upon successive stimulations. With regard to the second point,—that if eye-movement had anything to do with the fluctuations, the after-images should have fluctuated together, and not independently of each other,—we urge that the conclusion does not by any means follow from the premisses. It is true, as is pointed out by Hering, that both areas of the retina had been stimulated for the same length of time; and that, so far, the after-images should have been affected alike by eye-movement. But Hering overlooks the fact that the one after-image had been fading for 10 sec.

before the stimulus to the other was removed. It had thus run a large part of its course before the other began, and hence might be expected to disappear under a range of movement that would scarcely dim the other. We cannot only say that eye-movement may have been the cause of the independent fluctuation, but we can go farther and say that the after-images behaved precisely as they should have done if eye-movement were the cause of their fluctuation.

But farther, Hering's result, as well as his conclusion, must be called in question. The writer has tried the experiment upon himself and a number of observers, and so far from finding Hering's results invariable or even typical, has rarely met with a case in which, after the first couple of fluctuations, the one strip disappeared as a whole while the other remained intact. Instead of that, the whole area formed by the two broad strips and the narrow contrast strip between fluctuated, either as a whole or in parts, as all after-images of a certain magnitude do. When the fluctuation was in parts, now a corner of the area would drop away, now a strip across the top, now an irregular patch here followed by an irregular patch there, etc., etc. When the area fluctuated as a whole, first the two outside strips would spread over the intermediate space, the whole area becoming dim in consequence; then the entire image would disappear. When observation was made on the closed lids, this experiment furnished an excellent demonstration of the relation of the 'streaming phenomenon' to fluctuation.[1]

Hering's arrangement failed to give successive fluctuation for the reason that the strips were too large for their distance apart. In this zone of the retina, the zone of fluctuation in parts, the area included in each disappearance was not large enough to include the whole strip. Had the strips been placed farther apart, or made smaller and placed as Hering directed, the successive fluctuations aimed at would have been uniformly obtained; but their occurrence it is plain, would in no wise have demonstrated the intrinsically oscillatory character of the underlying visual processes. Still better results, however, would have been obtained if the stimuli had been smaller and also placed farther apart. A square or rectangular after-image, large enough to include the strip-areas, would also have fluctuated successively in parts, the fluctuating area now and then corresponding to, or including, the two strip-areas, in turn. All these fluctuation phenomena are due to variation in the

[1] For a description of this phenomenon, see below, p. 114, and for an explanation of its relation to the after-image, p. 123. The stream could be plainly seen to diffuse the color or gray of the two outside strips over the intermediate strip, and finally to blot out the whole image.

area of the retina involved, and have nothing to do with successive stimulation. Over a certain range of areas, fluctuation in parts is the invariable occurrence, whatever the temporal character of the stimulation.

We may now sum up the discussion of this experiment. So far from showing by his special device of successive stimulations that eye-movement cannot be the cause of fluctuation, and so far from throwing any difficulty in the way of the eye-movement hypotheses, Hering has succeeded rather in making it easier to explain, by eye-movement, the results which he obtained. In other words, he has produced the phenomenon of fluctuation in parts in the only way, known to the writer, in which it admits of ready explanation by the theories of Fechner, Helmholtz, and Fick and Gürber. In terms of any eye-movement hypothesis, the difference in intensity of the two after-images is amply sufficient to explain why a given eye-movement should not affect both of them alike. Hering's results would have been more difficult to explain had he used simultaneous stimulation. It is much more difficult, *e. g.*, to say in terms of eye-movement why after-images of a certain area fluctuate in parts, or why small after-images due to simultaneous stimulation of different parts of the retina fluctuate independently of one another. The fluctuation in the case both of simultaneous and of successive stimulation is, however, of the same nature, and its cause must, evidently, be assigned upon other grounds than those here given by Hering.

(4) As a final step in his argument, Hering maintains that, in order to a final decision of the question whether eye-movement exerts any influence upon the disappearance of the after-image other than by causing changes in the illumination of the retina, the course of the after-image must be traced in a darkened field of vision. He maintains that under these conditions eye-movement does not noticeably alter the natural course of the after-image, much less cause it to disappear. A few sentences further on, however, he qualifies this statement by the remark that, when observing in a dark-room, he was never able entirely to blot out an after-image that was at all distinct or intensive, by moving the eyes.[1]

[1] "In den ersten Paragraphen meiner Mittheilungen zur Lehre vom Lichtsinne habe ich eine Reihe von Erscheinungen besprochen, welche man an Nachbildern im geschlossenen und verdunkelten Auge beobachtet. Ich hatte bei solchen Versuchen reiche Gelegenheit festzustellen, dass Augenbewegungen den gesetzmässigen Verlauf dieser Nachbilder gar nicht merklich beeinflussen. Auch habe ich zahlreiche Versuche in einem Zimmer angestellt, welches völlstandig verdunkelt werden konnte, nachdem ich mir das Nachbild erzeugt hatte. Hier hatte ich den Vortheil, die Augenbewegungen bei ebenfalls offenen Augen ausführen zu können. Nie war es möglich ein irgend

Apparently, there is here a tacit admission that eye-movement causes weaker or less distinct after-images to disappear. If so, the argument against it as a causal factor is materially weakened; for, as has been stated earlier in the discussion, intensive after-images do not fluctuate at all. They must become sufficiently dim if fluctuation is to set in. In any event, however, observation is the court of final appeal. We must determine, first, whether eye-movement does cause after-images, weak or strong, to disappear when they are observed in a darkened field of vision; and secondly, whether the point at which fluctuation begins roughly coincides with the point at which eye-movement first causes the after-image to disappear. A series of experiments was conducted to this end. Many stimuli were used, colored and gray, and the after-images were observed under the following conditions: with the eyes closed and carefully covered by a black cloth; in the dark-room, with the eyes both open and closed; and in the blackness cylinder. In every case eye-movement caused disappearance when the after-image had become sufficiently dim, and this point roughly corresponded with the point at which fluctuation began. The following results, which are typical, have been selected for publication. In this case the stimulus was a square of Hering white paper, 5 by 5 cm., on a background of Hering gray no. 31; and the after-image was observed with the eyes closed and covered with a black cloth. Miss Alden, a graduate student in psychology in the University of Colorado, acted as observer. The time of stimulation was 40 sec., and the distance of the observer from the stimulus was 75 cm. The recording apparatus consisted of kymograph, telegraph key and electro-magnetic recorder, and electro-magnetic time-marker in circuit with a small chronometer set to half-seconds. When the disappearances were caused by eye-movement, the eyes were moved every 3 sec., at a signal from the experimenter. It may be well to add that the results showing the closest approximation have not been chosen for publication. In the case selected, too much eye-movement was prescribed. The after-image began to fluctuate at a greater intensity than in the companion series of natural fluctuations. There were more frequent fluctuations, and the average phase of visibility was shorter. Erring as they do, however, on the side of making eye-movement too effective, these results tell more strongly against Hering's assertion that eye-movement does not cause disappearance in a darkened field of vision than do the results

deutliche Nachbild durch Augenbewegungen, auch wenn sie ungewöhnlich gross und lebhaft waren, zum verschwinden zu bringen." In v. Graefe's Archiv, XXXVII, 2, 1891, 23.—*Cf.* also S. Exner, Zeits. f. Psychol., I, 1890, 47.

which show a closer approximation. For this reason, and also because about the same amount of eye-movement was prescribed as in the other duplication experiments which had already been carried out, this particular series has been selected.

TABLE I

A. Showing results for a darkened field of vision when the fluctuations were natural, and when they were produced by voluntary eye-movement. Unit 1 sec.

TYPE OF FLUCTUATION	NO. OF FLUCT'S	1st VIS.	AV. VIS.	TOTAL VIS.	AV. INVIS.	TOTAL INVIS.	VIS. + INVIS.
Natural	7	9.9	6.6	46.2	2.2	15.4	61.6
Produced by Voluntary Eye-movement	8	6.2	4.8	38.4	2.5	20.0	58.4

With regard to the natural fluctuation of after-images, when observed in a darkened field of vision, Hering says: "An den ersterwähnten Nachbildern (*i. e.*, those due to a bright object seen on a dark ground, fixated for 10-30 sec.) aber erfordert es sogar besondere Aufmerksamkeit wahrzunehmen, dass das negative Nachbild nach längerem Bestehen nicht bloss vorübergehend verschwindet, sondern dass sich zwischen sein Verschwinden und eventuelles Wiedererscheinen eine schwache positive Phase einschiebt, die freilich oft genug überhaupt nicht merklich wird."[1] It is difficult to determine whether this statement means that the weak positive phase occupies all of what usually passes for the phase of disappearance, or only a part of it. If it occupies the whole time, there is of course no intermission in the after-image process. The disappearance usually observed is merely an artifact, produced by observation with the retina illuminated. In view of this uncertainty it seemed worth while to repeat the experiments. Hering says that the recurrence of the positive phase may be observed if one fixates a bright object on a dark ground for 10, 20, or 30 sec., and then watches the after-image in a darkened field of vision. A square of white paper on a dark ground was taken as stimulus. This gave, as negative after-effect, a black square with a distinct contrast border of brilliant white on a very light gray ground. The black square fluctuated frequently; but there was never left in its place, nor did there ever appear anything that resembled, a square of white or light gray. When it disappeared, however, some part of the contrast border at times remained momentarily visible and often could be seen to

[1] *Op. cit.*, 18.

reappear slightly in advance of the black square;[1] but this phenomenon could scarcely be mistaken for a weak phase of the positive after-image. A small, irregular patch of slightly luminous haze is also frequently noticed about the point of regard.[2] But this occurs just as frequently during a phase of invisibility when the eye has been exposed to a colored or white stimulus, or in the darkened field of vision when the retina has undergone no local stimulation at all; hence it cannot be a positive after-effect of stimulation.

In order to make the test-conditions still more favorable to Hering, we substituted for the dark gray background prescribed by him a light gray (Hering no. 15). Under the original conditions, the positive phase must have been difficult to distinguish, had it occurred. The negative after-effect now obtained was a black square upon a ground of gray such that not only would the lighter positive phase have been easily distinguishable, if it occurred, but that it would also have been considerably intensified by contrast. Still the positive phase could not be detected during the periods of invisibility of the negative phase.

When the stimulus is luminous, Hering says that the positive phases are plainly present, alternating with the negative. As before, two experiments were made upon this point by our observers: the one with the background light, but not so bright as the stimulus; and the other with the background dark. In the first experiment, the sun's disc and Colorado daylight served as stimulus and background. The bright background intensified the darkened field of vision in the after-effect, and thus, as far as brightness was concerned, favored by contrast the observation of the positive phase of the after-image. The eye was stimulated, probably, from 1 to 3 sec. The observations were made in mid summer, near the middle of the day. The sky was cloudless, and the light very intensive. While, now, it is difficult to decide what is positive, and what negative, in the color changes that follow exposure to a brightly

[1]This, of course, is merely an instance of fluctuation in parts. The area that was swept out by the stream, or complex of streams, did not at first include this particular part of the contrast border; but soon, owing to the spread of the area of commotion, the contrast border became involved in the disappearance. The reappearance of a part of the border in advance of the remainder of the after-image is a phenomenon of the reverse order. The border was cleared of the streaming material before the rest of the image.

[2]Close observation shows this to be a centre of activity of a 'streaming' area. It also occurs, but less noticeably, in other parts of the field of vision more remote from the point of regard. Such patches are usually found to be the foci or places of intersection of narrow, swiftly moving streams.

luminous stimulus, still our observers reported, here as in the former experiments, unquestionable, well defined phases of disappearance. Voluntary eye-movement also produced disappearance when the after-image had reached the dimness at which fluctuation begins.

When exposed to the sun's disc, the eye was purposely moved in order that the after-image might be jagged and irregular. This was of some advantage for observation, because the limbs of the after-image, owing to their less intensive stimulation, passed through the color changes slightly in advance of the body. The after-image was observed with the eyes closed and covered with a black cloth. The following report is typical:

There was first a momentary lasting over of the stimulus in the body of the after-image, while the edges were a deep red. The body then changed to a light blue. The red border, in the meantime, had been gradually extending inwards, especially in the limbs of the image.[1] The edges of the central blue patch next began to change to a yellow-green. While this change was going on, the outer margin of deep red was encroaching, more and more, upon the centre. When the central portion had become almost entirely yellow-green, the marginal red had taken on a border of deep blue.[2] All the central portion next became yellow-green. The red border encroached still farther upon the centre, and was in turn encroached upon by its border of dark blue. The centre then showed a tendency to become light blue again. Finally, the whole image became a deep red with a dark blue margin. This stage lasted for a comparatively long time, and disappearances were frequent. Next, the dark blue of the margin spread gradually over the entire image. There were later a few faint recoveries (following disappearances) of a lighter blue; then came in order a light red-violet, a violet-blue, and a dull dark yellow. In these last fainter stages complete disappearances were especially frequent.

The fluctuations observed in this experiment were not different from those occurring under the usual conditions. The

[1] At this stage, there was a very noticeable effect of perspective. The red seemed to be projected farther into the background than the blue, farther back even than the general field of vision, as if it were sunk or seared into the field. The blue seemed a detached and floating patch, which was now and then swept away by a stream, changing its shape as it went, and dissolving in the stream body.

[2] These changes were not all gradual or continuous. Sometimes the central patch would change from light blue to the next stage, yellow-green, and back again; at times it would go from blue to the deep red, and back to blue again; and sometimes it would disappear entirely, frequently repeating in its reappearance all the color stages in their inverse order. Sometimes it would come back suddenly to the color from which it fluctuated; and, very occasionally, the order would be irregular. These changes were always connected with the streaming phenomenon. Light streaming, apparently, caused the changes from color to color, while heavy streaming blotted out the image entirely. Recovery came with the clearing away of the streaming material.

after-image fluctuated as a whole, and in parts, as all after-images do. Now one of the limbs would drop off; now the lower part, now the upper; now the image would disappear across the centre; and again it would disappear completely. In fact, this experiment, so far from furnishing evidence against fluctuation, gives (owing to the long duration of the after-image) an unusually good demonstration of the various phenomena that characterize fluctuation.

Experiments were also made with a dark background. Here, as before, observation showed clearly marked periods of disappearance. The intermission was absolutc. No part of the interval was occupied by anything that could be identified with a recurrence of the positive phase at low intensity. Further details appear needless, as the conditions already described were more favorable than those of the dark ground for the observation in question.

It is logically impossible, then, to conclude from the foregoing experiments, as Hering does, that eye-movement is ineffective in the disappearance of the after-image, or that fluctuation is merely the alternation of negative with weak positive phases of the after-image. It is obvious, rather, that eye-movement is able to cause the diappearance of any after-image that will fluctuate.—

b. Exner argues against the view that intermittence is grounded in the nature of the after-image process. It is a well-known fact, he says, that eye-movement will cause an after-image to disappear. Nor does eye-movement affect the after-image process. The eye, moving in some particular direction, causes the field of vision to travel across the retina in the opposite direction. This moving field of vision, by distracting from the perception of the after-image which is stationary upon the retina, causes it to drop out of clear consciousness. When the eye comes to rest, the distraction is removed, and the after-image reappears.[1] Now, this explanation accounts, at best, only for our inability to see the after-image while the field of

[1] Exner and Hering thus agree, though from different points of view, that there is no particular virtue in eye-movement to cause the disappearance of the after-image. Movement of the background works just as well. It is worthy of notice, however, that while Hering uses the statement as an argument for the oscillatory theory, Exner uses it as an argument against. Exner thinks it evident that movement of the visual field distracts from the clear perception of the after-image just as it distracts from the clear perception of objects actually in the external visual field; and explains the whole effect of movement of the background in this way. It is an easy step, then, to infer that the disappearances produced by voluntary eye-movement are to be similarly explained, and to refer the fluctuations occurring under the conditions of normal fixation to involuntary eye-movement rather than to oscillation of visual processes.

vision is in motion. It does not account for the invisibility of the image after the eye has come to rest. There are, however, two cases of this inability to see the after-image while the field of vision is in motion. In the one, the after-image is vaguely seen throughout, but cannot be seen clearly so long as the eye is in rapid movement. It comes out at once when the motion lags or ceases. This corresponds to Exner's distraction phenomenon; but it is not what is ordinarily meant by disappearance. The other is a case of true disappearance. The after-image goes out absolutely. It does not reappear as the motion lags, and is still invisible after the eye has accurately regained its fixation. In the writer's experiments upon fluctuations produced by voluntary eye-movement, a disappearance was not recorded unless the after-image remained invisible after the observer had accurately regained his fixation. Disappearances of this sort were evidently not due to distraction, for distraction had ceased before the record began.

Although Exner thus seems to be mistaken in his view of the disappearance produced by eye-movement, his theory will be put to experimental test. A direct corollary from it is that the effect of eye-movement upon the disappearance of the after-image bears an inverse relation to the uniformity of the projection field. There are three sets of conditions under which this relation should obtain: (*a*) disappearance under the conditions of ordinary fixation; (*b*) disappearance produced by voluntary eye-movement; and (*c*) disappearance caused by movement of the background. It certainly does not obtain under the first conditions. The after-image fluctuates with equal readiness when projected upon lettered surfaces, upon mottled engine-gray cardboard, upon either the dull or the glazed surface of milk glass (than which there is probably no more uniform background), and upon the Hering gray papers. Nor does it seem to make any difference which of the above backgrounds is used, when the disappearance is caused by voluntary eye-movement. The inverse relation does, however, seem to hold, within limits, when the disappearances are caused by movement of the background; the mottled backgrounds have, apparently, more effect than the uniform. Now it is evident that the mottled background, travelling across the retina, could distract no more from the perception of the after-image in this case than in the other two. It would, however, in proportion to its irregularity, distract from steady fixation. Thus the difference is to be explained in terms of increased eye-movement; and again the argument against eye-movement, upon more careful investigation, is converted into an argument for some sort of eye-movement hypothesis.

As the matter stands, then, with regard to Hering and Ex-

ner, eye-movement must still be taken into account in the explanation of the fluctuation of the negative after-image.

ii. *Demonstration of causal connection between eye-movement and fluctuation, as against the theory of intrinsic oscillation.*

a. Results in general.—In order that the thread of the argument may not be lost in the tables and details that follow, a brief general statement of results is here given.

(1) *Fluctuation occurs only within a limited range of after-image areas.* It is a matter of common laboratory report that fluctuation does not take place in the after-effect of general adaptation. The after-effect dies away gradually. There are none of the intermittent variations of intensity that characterize the after-effect of local adaptation to stimuli of certain areas. This fact is brought out in practically all the record-books kept by members of the junior training course at Cornell University. Careful tests have also been made, with the same result, by the help of observers trained to work with just noticeable differences, by whom even slight variations in intensity would have been noticed.

We turn to the after-effect of local adaptation. Here we find that fluctuation occurs only within a comparatively limited range of after-image areas, varying somewhat for the different colors used, and for different observers. Large after-images do not fluctuate at all; small after-images little, if at all; after-images of mean area alone fluctuate readily. If a curve of frequency were plotted with the areas laid off along the ordinate and the frequency of fluctuation along the abcissa, the curve would start close to the abcissa, rise gradually until a certain area was reached, and then bend down rather more sharply to the abscissa. This result is, apparently, incompatible with the hypothesis of intrinsic oscillation. Absence of fluctuation for a single area would tell strongly against that theory; and such a range of variation as is expressed in the curve of frequency would seem to condemn it absolutely. The shape of the curve of frequency, together with the fluctuation in parts of after-images of certain areas, is the most difficult problem that the fluctuation of the after-image presents to theory. That eye-movement, acting in co-operation with streaming, offers a satisfactory explanation of all the variations resulting from change in area will be shown in detail in its proper place.

(2) *Whatever renders fixation unsteady increases the frequency of fluctuation and decreases the duration of the after-image.* The converse is also true: whatever aids fixation decreases the frequency of fluctuation and increases the duration of the after-image. Various methods were used to disturb and to control fixation. In every case records of eye-movement were

taken, that showed both the range and frequency of the movements and the total time during which the eyes were in motion. A quantitative comparison could thus be instituted between these movements on the one hand, and the frequency of fluctuation on the other. The results show a high degree of correlation.

(3) *The form of the stimulus affects the frequency of fluctuation.* Experiments were made with squares and with narrow strips of equal area. The latter showed a much greater liability to fluctuation. This result can hardly be explained on the theory of intrinsic oscillation; the oscillatory character of the retinal processes must be sensibly the same within a square as within a narrow oblong area. There is, however, good reason to believe that eye-movement differs in the two cases; for when the strip is observed, the introspective reports of the observers bear witness to a strong conscious tendency to look towards the ends, to see what is happening there. The tendency to increased movement with the strip-images is shown also in the eye-movement records. Eye-movement, then, is a factor in the result. Another and, as we shall see later, a very important factor is the retinal distribution of the zones of streaming.

(4) *The arrangement of the stimulus with reference to the direction of greatest eye-movement affects the frequency of fluctuation and the duration of the after-image.* A strip after-image, placed with its breadth in the plane of the greater range and frequency of eye-movement, fluctuates more frequently and has a shorter duration than in the inverse arrangement. The greater frequency of fluctuation is due to the action of the greater amount of eye-movement upon the lesser dimension of the after-image. The point may be demonstrated as follows. Let the disappearance be produced by voluntary eye-movement. If these movements are in the horizontal plane, disappearance is more frequent when the breadth of the strip is in the horizontal than when it is in the vertical plane. Conversely, if the eye-movements are in the vertical plane, disappearance is more frequent when the breadth of the strip is in the vertical than when it is in the horizontal plane. An explanation will be given in Section iii, *c*. Were a periodicity grounded in the nature of the after-image process, extraneous influences, like the form and arrangement of the stimulus, ought not thus to affect the frequency of fluctuation.

(5) *The results grouped under (1), (3) and (4) can be roughly duplicated if voluntary eye-movement is brought in to cause fluctuation.* In the experiments under this heading, the same squares were used as in (1); the same strips and squares as in (3); and the same strips and arrangements with reference to the direction of greatest eye-movement as in (4). The cor-

respondence in the results of the two series of experiments is extremely high. Here, then, is a strong indication that eye-movement is a causal factor in fluctuation. Another factor, however, is required for the complete explanation of the results. The methods employed in (1) and (3) were especially devised to vary the amount of involuntary eye-movement from observation to observation. Yet their results were approximated by the introduction of voluntary eye-movement, the amount of which was kept constant from one observation to another. Obviously, therefore, a second factor is at work, which is affected by eye-movement, and which in turn acts upon the after-image. A more complete explanation is given later in terms of streaming.

(6) *An increase of the time of stimulation increases the number of fluctuations of the after-image.* The time of stimulation ranged for the different observers from 10 to 100 sec. Increase of the time of stimulation brought with it an increase in the intensity of the after-image, an increase in eye-movement (shown by the records), and an increase in the fluctuation of the after-image. It cannot, of course, be determined off-hand which of the first two variations is the cause of the third. From the evidence already at hand, it seems probable that eye-movement is responsible for the increase of fluctuation. Moreover, there is no obvious reason why a more intensive after-image, on the ground of its intensity alone, should begin to fluctuate sooner (at a greater intensity) or should fluctuate more frequentiy after it does begin,—as happens uniformly under the present conditions. The problem is, however, capable of definite experimental analysis. Increase of intensity can be obtained by a method which does not cause an increase of eye-movement; namely, by increase of the intensity of the stimulus. In this case there is no increase of the number of fluctuations. We thus have new and positive evidence that eye-movement is a causal factor in fluctuation. A long period of fixation increases involuntary eye-movement, and this again increases the frequency of fluctuation, apparently in the same proportion.

(7) *The observers most sensitive to the methods used to distribute fixation showed the widest range of variability of fluctuation and duration.* The observers ranged from very stable to very sensitive. The tables show a variation in results from individual to individual, corresponding to the differences in sensitivity to disturbances of fixation. Thus, B and A were very sensitive, W much less sensitive, and M the least sensitive of all. Correspondingly, B's and A's results are very different for the different variations; W's less, and M's still less different. This correlation, it is clear, furnishes evidence in favor of eye-move-

ment as clear-cut and decisive as that to be drawn from the changes in result produced by the different methods in the case of a single individual.

(8) *Increase of practice in fixation brought with it a decrease in the frequency of fluctuation and an increase in the duration of the after-image.* Towards the close of the semester's work it became clear from the eye-movement records that there was an increased ability to fixate on the part of all the observers. There was also a corresponding decrease in the frequency of fluctuation. The pitch of the curve of frequency for the method of areas, *e. g.*, was lessened. At both ends of the series, areas that had fluctuated earlier would not now fluctuate at all, and areas that formerly fluctuated readily now underwent fewer fluctuations. The effect of practice was especially marked in the case of M. There was also, as the work advanced, a decreased sensitivity to the methods used to disturb fixation. With practice fixation became progressively more stable. A general straightening of the frequency curves, for all the methods employed, was the result.

b. General description of method and apparatus. All methods were ruled out as ineffective that did not produce changes in result markedly greater than the variations occurring from time to time without change of experimental conditions. Experiments were planned in series to be finished at a single sitting. Results obtained at different sittings were never compared directly, nor were the results from broken or interrupted series included in the general averages. The order of presentation of the members of a series was changed from time to time, in order to rule out time and practice errors. Care was taken in the selection of *O*'s to get a random sampling of types both as to visual organization and as to experience. As little as possible was left to the uncontrolled introspection of the *O*'s. The analyses were provided for in the experimental variations, and the *O*'s were asked only for the simplest judgments, and were kept in entire ignorance of the problem and plan of experimentation.

The recording apparatus used throughout consisted of kymograph, telegraph-key and electro-magnetic recorder, with electromagnetic time-marker regulated by a chronometer set to half-seconds. The experiments were conducted in a long optics room lighted at the one end by two windows reaching from near the floor to the ceiling. The *O*, head in rest, was seated between these windows, so that the light coming from either side and above fell upon the projection-field of engine-gray cardboard 75 cm. in front. The time of stimulation, unless otherwise stated, was 40 sec., and the unit of record was 1 sec.

c. Results in detail. The work was begun three years ago

in the Cornell University laboratory, and continued in the laboratory of the University of Arizona during the year 1905-6; in the laboratory of the University of Colorado during the fall semester of 1906-7; in the Cornell University laboratory during the spring semester of 1906-7; and finished in the laboratory of Bryn Mawr College during the fall semester of 1907-8. The results have been verified both in drill courses and in research, with a wide range of observers of diverse training and experience. The present section of the work was done for the most part in the laboratory of the University of Colorado. A part of it has been repeated in the laboratory of Bryn Mawr College. The following persons served as observers: Professor J. H. Bair (B); the Misses Alden (A), Walter (W), Montgomery (M) and Wright (Wr), students in his laboratory; and Miss Stout (S), a student in the laboratory of Bryn Mawr College.

In the tables account is taken of the following points: the number of fluctuations, the first phase of visibility, the average of the phases of visibility, the sum of the phases of visibility, the average of the phases of invisibility, the sum of the phases of invisibility, and the sum of the phases of visibility and invisibility. One less than the number of phases of visibility has been taken as the number of fluctuations. The last disappearance has not been counted in estimating the number of fluctuations. This number is of value to us as a measure of the disturbance in the after-image process. A still better measure, however, is the frequency of fluctuation, expressed by the average of the phases of visibility. The length of the first phase of visibility is of importance as indicating at what intensity the after-image begins to fluctuate. In general, the stronger the operation of disturbing factors, the greater should be the intensity at which the after-image begins to fluctuate. Accordingly, then, we should expect an increase of eye-movement to decrease the first phase of visibility, and a decrease of eye-movement to increase it.

The conventional use of the term duration has been departed from in this discussion. By duration is here meant the sum of the phases of visibility. This use of the term is in the first place strictly accurate, so far as we have any immediate presentation to consciousness of the after-image process; and, so considered, it has, in the second place, more direct bearing upon the problem of the restoration of the adapted stimulus.

No especial significance is attributed to the phases of invisibility. They are included in the tables merely that a complete account of the temporal course of the after-image may be given.

(1) *Fluctuation occurs only within a limited range of areas.*

This statement holds of all the colors used: Hering standard red, green, blue and yellow. The result varied somewhat, however, for the different colors. The red after-image showed itself throughout to be the most instable. It fluctuated most frequently, had the shortest duration, and was most affected by the various disturbances. At the other extreme was the yellow after-image. It proved the most stable of all. For this reason, since space does not permit of giving results from all the stimuli, the yellow image derived from Hering blue as stimulus has been selected for the following tables; it affords the most rigid test of the effect of eye-movement on the temporal course of the after-image in general.

Areas ranging from .5 by .5 cm. to 61 by 50 cm. (the latter being the dimensions of a single sheet of Hering paper) and viewed at a distance of 75 cm. were employed. A still larger area was required for some observers, if no fluctuation was to ensue. This increase in size was obtained by moving the stimulus nearer to the observer.

It will be noticed from the tables that, with small areas, little or no fluctuation occurs. Then there is increase up to a certain point, namely, 10-20 cm. square, when decrease begins. Fluctuation disappears entirely in the neighborhood of 60-65 cm. square.

If we ask how far eye-movement is to be regarded as a causal factor in the increased fluctuation from small to medium areas, and its consequent decrease, we find the following evidence. Over the range of areas showing increase of fluctuation the observers spoke of a strong conscious tendency to look away from the fixation point in order to see what was happening towards the margins. This tendency constituted a distracting factor for fixation. With small areas, the whole after-image lay within the field of direct observation; consequently there was nothing to distract fixation. With the next set of areas, the edges passed into the field of indirect observation, but were still noticeable. Hence they disturbed fixation in various ways. In the first place, they broke the uniformity of the field of vision; and in the second place the observer was instructed to register only total disappearances, disappearances over the whole area. The margins were not clearly visible, and so tempted the eyes to a readjustment which would bring them into the field of clear vision, and thus make observation easier. With the third set of areas, the margins had passed so far from the field of direct observation as to be of little concern to the observer. The field was of an uniform color and brightness, and the margins did not compel attention.

The eye-movement records confirm these introspections. There is increase of movement through the range of areas

TABLE II

A. Fluctuation occurs only within a limited range of areas. Results showing the effect of variation of area on the fluctuation of the after-image.

Area	No. of Fluctuations	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
.5x .5cm.	0	18.7	18.7	18.7	0	0	18.7
1.5x1.5 "	1	48.6	24.8	49.6	5.5	5.5	55.1
5 x 5 "	2	59.5	21.6	64.8	2.4	4.9	69.7
10 x 10 "	12	21.5	5 9	76.7	2.4	28.8	105.5
20 x 20 "	7	23.5	10.0	80.0	3.2	22.4	102.4
40 x 40 "	3	42.0	16.0	64.0	2.1	6.3	70.3
61 x 50 "	0	72.0	72.0	72.0	0	0	72.0

TABLE III. (Observer W.)

Area	No. of Fluctuations	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
1 x 1 cm.	2	14.7	20.2	65.5	1.6	3.3	69.8
5 x 5 "	2	18.0	27.9	83.8	1.0	2.0	85.8
10. x 10. "	3	15.5	21.1	85.0	1.0	3.1	88.7
20 x 20 "	6	21.0	11.6	81.3	3.9	11.8	93.1
40 x 40 "	5	8.8	10.5	63.2	4.3	21.45	84.6
61 x 50 "	1	35.5	31.6	63.3	2.6	2.6	65.9
61 x 50 " 55 cm. distant	1	60.0	47.7	95.5	1.0	1.0	96.5
61 x 50 cm. 35 cm. distant	0	50.5	50.5	50.5	0	0	50.5

showing an increase of fluctuations, and decrease where there is a decrease of fluctuation. Nevertheless, the explanation is not so simple as this correlation implies. The effect of eye-movement on fluctuation is not direct. Eye-movement affects the after-image only through its effect on the streaming phenomenon; and the final word of explanation must be deferred until we come to discuss that subject.

Two methods were used for the investigation of eye-move-

TABLE IV. (Observer M.)

Area	No. of Fluctuations	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
1.5 x 1.5 cm.	0	52.0	52.0	52.0	0	0	52.0
5 x 5 "	2	27.3	18.4	55.2	1.3	2.5	57.7
10 x 10 "	6	35.5	7.9	55.3	2.5	7.5	62.8
20 x 20 "	6	35.0	8.0	56.4	1.3	7.8	62.2
40 x 40 "	5	32.1	8.8	53.1	1.6	8.3	61.4
61 x 50 "	4	42.2	10.5	52.5	1.3	5.3	57.8
61 x 50 " 35 cm. distant	0	52.0	52.0	52.0	0	0	52.0

ment. In the first method, the shifting of the after-image from the stimulus during fixation was chosen as a measure of the eye-movements taking place. This method had the disadvantage that the eye-movement could not be recorded while fluctuation was going on. However, by using only experimental variations that produced marked changes in the steadiness of fixation, by alternating eye-movement with fluctuation records, and by taking a large number of records for each experimental device, this objection was practically obviated; more especially as only comparative results were desired. The method, too, has the very great advantage of sensitivity. When, *e. g.*, the observer is stationed 1 meter from the stimulus, a shift of the after-image 1 mm. to either side represents an eye-movement (measured by the chord of the arc) of approximately .017 mm.[1] The sensitivity of this method is directly proportional to the distance of the observer from the stimulus, and is limited only by the range of distinct vision. Under favorable conditions exceedingly slight tremors can be detected. In fact, as a gauge for small eye-movements, the method is far more sensitive than the methods of photography and of mechanical registration.

In the second method, the after-image was projected without a fixation point, and a record was made of the time during which it was moved and of the time during which it was still. This method was somewhat defective, because the range of movement (a very important factor in the causing of fluctuation) could be indicated only roughly, by the introspective

[1]Calculation is made from the average of the first and second principal focal distances of the normal eye as estimated by Listing: see Helmholtz, Physiol. Optik, 90.

reports of the observers as to whether the after-image moved rapidly or slowly. However, it proved a valuable supplement to the former method, since by it the eye-movements were registered while the fluctuations were actually going on. One could thus tell at once whether disappearance came as a direct effect of eye-movement, *i. e.*, whether it came while the eye was moving or immediately after it had moved; or whether it came in an interval of rest. The effect of vigorous, quick movements could also be compared with that of weaker and slower movements.

Two forms of this second method were employed. In the one, the eye-movement and the phases of appearance and disappearance of the after-image were both recorded; in the other, the eye-movements alone were recorded. The first form gave a direct tracing of the effect of eye-movement upon fluctuation. The recording was done as follows. The after-image was projected without a fixation point, and the key was held down as long as the after-image was in motion and released when it came to rest. When the after-image disappeared, the key was given two quick pressures, and then released until the after-image returned, when the record of movement went on as before until the next disappearance. A certain complication arose with this form of the method. The effort to record both eye-movement and fluctuation seemed to interfere with the course of the after-image, so that fluctuation occurred more frequently than when fluctuations alone were recorded. However, the change was merely a general rise in the scale of frequency. The variations from device to device stood out just as plainly as when the alternative method was used. The reason of the more frequent fluctuations is, probably, that the divided attention necessitated, or rather that the rapidly alternating direction of attention resulted in, a less steady fixation. On this account, the records that were meant to show simply the variation in eye-movement due to the various devices were taken according to the second method: eye-movement alone was recorded. Only these results will be given here, since the others cannot be adequately stated in tabular form,and space forbids the separate publication of every set. The statement must suffice that causal connection between eye-movement and fluctuation is directly evident upon the inspection of the results in question.

For the investigation of the effect of variation of area upon eye-movement, the second method (second form) was used. The after-images were projected without aid from fixation; and the key was held down as long as they were in continuous motion, and released during the intervals in which they were at rest. The following results were obtained.

TABLE V

A. Eye-movement with variation in the area of the stimulus. Showing that an increase in the area of the stimulus first increases, then decreases, the involuntary eye-movement occurring when the after-image is observed.

Area of Stimulus	Time Observed	Time Moving	Time Still	Time Moving ÷ Time Still	Rate of Movement
.5 x .5cm.	14.5	4.5	10.0	0.45	Slow
1.5 x 1.5 "	19.5	6.4	13.1	0.48	"
5 x 5 "	28.3	10.5	17.8	0.59	"
10 x 10 "	34.0	26.45	7.55	3.50	Fairly Rapid
20 x 20 "	37.0	20.5	16.5	1.24	Moderate
40 x 40 "	65.2	24.5	50.7	0.59	Slow
61 x 50 "	58.0	19.4	38.6	0.50	"

TABLE VI. (Observer W.)

Area of Stimulus	Time Observed	Time Moving	Time Still	Time Moving ÷ Time Still	Rate of Movement
1 x 1 cm.	52.0	15.0	37.0	0.40	Slow
2 x 2 "	58.5	17.1	41.4	0.41	"
10 x 10 "	62.0	23.3	38.7	0.60	"
20 x 20 "	68.0	37.5	30.4	1.23	Fairly Rapid
40 x 40 "	87.0	46.26	40.74	1.13	"
61 x 50 "	96.2	21.3	74.9	0.28	Slow

(2) *Whatever renders fixation unsteady increases the frequency of fluctuation and decreases the duration of the after-image.* The stimulus was a square of standard Hering blue, 3 by 3 cm., fastened upon a large square of engine-gray cardboard. A square of the same cardboard was used as a background upon which to trace the course of the after-image. The effectiveness of the methods employed to disturb fixation was determined by records which showed the range and frequency of the eye-movements produced, and the total time during which the eyes were moving. The methods themselves were five in number. (*a*) The stimulus was fixated at its centre, and the after-image was projected without a fixation-point. (*b*) The stimulus was fixated at its centre, as before, and the after-image

TABLE VII. (Observer M.)

Area of Stimulus	Time Observed	Time Moving	Time Still	Time Moving ÷ Time Still	Rate of Movement
1.5x1.5 cm.	50	7.6	41.5	0.18	Slow
5. x 5. "	56	25.0	31.0	0.80	"
10 x 10 "	60	41.5	16.5	2.50	Fairly Rapid
20 x 20 "	58	40.5	19.5	2.08	"
40 x 40 "	60	39.8	20.2	1.98	Moderate
61 x 50 "	58	35.2	22.8	1.54	"
61 x 50 " (35cm. dis.)	57	21.4	35.6	0.60	Slow

was observed by help of a fixation-point. All the observers, with one exception, found the point of service for holding the after-image steady. The exception was Dr. Bair, for whom any effort at muscular control resulted in involuntary twitchings. In his case, therefore, the eye-movement records showed a greater unsteadiness of regard, when effort was made to fixate the point, than when the image was traced upon the blank surface of the cardboard. (*c*) When the after-image was projected without a fixation-point, it tended uniformly to move off in some particular direction, varying with the observer. Whatever be the explanation of this phenomenon (it may possibly be due to a faulty centering of the image upon the retina, itself the result of some maladjustment of the visual mechanism, —movement resulting as a reflex tendency to more accurate fixation), advantage may be taken of it to exaggerate or to correct eye-movement. In order to exaggerate the movement, the direction of the tendency was carefully determined at the beginning of the experimental series. The stimulus was then fixated at a point placed in the line determined by this tendency to movement, but in the *opposite* direction from the centre of the stimulus. Part or all of the stimulus was thus thrown into indirect vision, and the tendency of the after-image to move was increased,—seemingly in proportion of its displacement from the central portion of the field of vision. The reflex movement which tends to centre the after-image in the field of vision added to the natural tendency to movement; and the after-image, projected without a fixation point, moved off rapidly in the direction planned. (*d*) To correct the tendency to movement, the stimulus was fixated at a point placed in the line of the movement, but in the *same* direction from the centre of the stimulus. The consequent displace-

ment of the after-image set up a tendency to movement which counteracted the natural tendency. By careful adjustment it was possible to obtain a fair balance of the two factors, so that the after-image was held steady when projected without a fixation point. Even under the rough conditions of our experiments this adjustment proved, for some observers, the best method of controlling fixation that we could devise.[1] (*e*). For some observers, the best aid to fixation was found to be a square, drawn on the cardboard, of exactly the same size and shape as the after-image, with a point placed at its centre. When the eye moved, the after-image was observed to slip from the square frame; and the observer was thus able to correct the movement before it had attained any considerable range. With the combination of square and central point, the observer had the double advantage of the aid to fixation and the conscious check upon movement. With the point alone, there is little or no conscious control of movement; for the point has to move so far into the field of indirect observation that it is recognized as occupying a different position before the control is operative and the eye can refixate. The distraction to fixation presented by the sides of the square was probably little, because the figure was small enough to be included, practically as a whole, in the field of direct observation. At all events, it did not offset the advantage in the cases of M, A, and Wr.

For A, the after-image, projected without aid to fixation, first moved off slowly to the left, but soon turned sharply and moved much more quickly up and to the right, the latter being the stronger component in the movement. All fluctuations occurred during the second phase. Hence the drift to the left was disregarded in the methods used for correction and exaggeration. To exaggerate the movement, the fixation point was placed 9 mm. below and 12 mm. to the left of the centre of the stimulus. To correct, it was placed 9 mm. above and 12 mm. to the right of the centre.

For B, the after-image moved up and to the right. To exaggerate this movement, the fixation point was placed 12.5 mm. below the centre of the stimulus and 10.5 mm. to the left. To correct, it was placed 8.5 mm. above the centre and 8.5 mm. to the right.

For W, the after-image tended to move up and to the right.

[1] The direction of the tendency to movement, for the different observers, will be stated in the discussion of the tables. For the students passing through the junior laboratory course, it seems most frequently upward or upward and to the right. The dominant component appears to determine the observer's type as to frequency and range of movement in the horizontal and vertical planes.

TABLE VIII

A. Whatever renders fixation unsteady increases frequency of fluctuation of the after-image and decreases its duration. Whatever aids fixation produces the opposite effect.

Variation	No. of Fluctuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis.+ Invis.
Square	1	44.0	25.0	50.0	6.0	6.0	56.0
With Point	2	39.2	15.8	47.4	5.7	11.4	58.8
Without Point	3	22.0	10.2	40.8	3.9	11.7	52.5
Exaggerated	5	9.5	4.0	24.0	1.4	7.0	31.0
Corrected	2	36.8	21.5	64.5	4.5	9.0	73.5

TABLE IX. (Observer B.)

Variation	No. of Fluctuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
With Point	10	17.5	3.1	34.1	1.3	13.0	47.1
Without Point	9	36.0	6.2	62.0	1.2	10.8	72.8
Exaggerated	14	26.0	1.1	16.5	1.0	14.0	30.5
Corrected	8	49.5	9.0	81.0	1.5	12.0	93.0

TABLE X. (Observer W.)

Variation	No. of Fluctuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
Without Point	4	13.0	15.2	76.0	.81	3.2	79.2
With Point	3	16.0	22.4	89.6	.55	1.6	91.2
Exaggerated	7	6.0	8.2	65.6	.52	3.6	69.2
Corrected	2	20.7	32.0	96.0	.50	1.0	97.0

Accordingly, to exaggerate this movement, the fixation point was placed 23 mm. below and 23 mm. to the left of the centre of the stimulus. The best correction of the movement was obtained by placing the point 12 mm. above and 6 mm. to the right of the centre. W's records showed an individual peculiarity, in that the first phase of visibility was relatively short, while the last was long. There is no obvious explanation.

TABLE XI. (Observer M.)

Variation	No. of Fluctuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
Without Point	5	8.7	7.0	42.0	3.7	18.5	60.5
With Point	2	24.0	24.1	72.3	.67	1.3	13.6
Exaggerated	6	2.4	4.3	30.1	1.1	6.6	36.7
Corrected	1	37.0	29.7	59.4	.9	0.9	60.3

For M, the after-image moved up and to the right. To exaggerate this movement, the fixation point was placed 12 mm. below the centre of the stimulus and 12 mm. to the left. To correct, it was placed 7 mm. above the centre of the stimulus and 7 mm. to the right.

For Wr, the after-image moved up and to the right. To

TABLE XII. (Observer Wr.)

Variation	No. of Fluctuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
Without Point	3	81.5	26.5	106.2	2.3	9.2	115.4
With Point	2	92.0	40.3	120.9	1.8	5.4	126.3
Exaggerated	3	45.0	17.2	68.8	1.5	6.0	74.8
Corrected	1	63.5	45.0	90.0	2.5	2.5	72.5
Square	1	71.2	42.0	84.0	2.8	2.8	86.8

exaggerate this movement, the fixation point was placed 11.5 mm. below and 11.5 mm. to the left of the centre of the stimulus. To correct, it was placed 10 mm. above and 10 mm. to

TABLE XIII

W. Showing the effects of voluntary control.

Variation	No. of Fluctuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
Without Point, No Effort	5	7.0	10.8	64.8	1.4	7.0	71.8
Without Point, Effort	3	16.7	19.9	79.6	1.1	3.3	82.9

the right of the centre of the stimulus. Wr's records showed very long phases of invisibility.

It was found that, when the after-image was projected without a fixation point, frequency of fluctuation was considerably increased if the observer made no particular effort to hold the eyes steady. The following results illustrate this point.

This method showed, more plainly than any other, the effect of a variation in the amount of eye-movement upon the frequency of fluctuation. For this reason, the eye-movements resulting from the various devices employed were studied with some care. Three cases were made of this determination: specimen results will be given from each one.

(1) In order to compare the movements occurring, first, when a point is given for fixation, and secondly when there is no such aid, we had recourse to the shift of the after-image from a colored strip. Strips of Hering's standard yellow, 5 by 50 mm., were pasted on a background of white cardboard, with the shorter dimension in the plane in which the eye-movement was to be investigated. To determine frequency, it was then necessary simply to record the appearance of the after-image to right or left, above or below the stimulus. Separate series were taken for each plane. For the determination of range of movement, narrow strips of paper of the same brightness as the background were pasted successively 2, 4, 6, 8 . . . mm. from the stimulus, and only those movements were recorded that shifted the image up to or beyond them. While the strips were inconspicuous, so that the eye was not drawn away from the fixation point, it was not difficult to observe when the image reached or passed them. The strips were also used when frequency alone was to be determined, in order that the same experimental conditions might obtain throughout. The record was made as follows. When the objects of investigation were the frequency of eye-movement, and the total times during which the eyes maintained and lapsed from their proper fixation, the observer pressed the key as the image appeared to either side of the strip, and held it down until the image was again superposed upon the stimulus. Then the key was released, and so on. Since the eyes may be said to have been in motion for practically the whole period during which the image was not superposed upon the stimulus, the method gives a record of the total time for which the eyes were still and of the total time for which they were moving. When, again, the range of movement was investigated, the key was held down only while the image was out as far as, or beyond, the strips which served as range indicators. These records, therefore, show only the times for which the point of regard was shifted a given distance from the fixation point and for which it was not.

The following tables also inform us of the direction of greatest eye-movement,—information which we need under (4) below.

TABLE XIV

A. Eye-movement: Results showing the movement in the horizontal and vertical planes, with and without a fixation point. Time of observation, 1 min.

Arrangement	Fixation	Range of Movement	No. of Movements of Given Range	A. Time Eye Moving with Given Range	B. Time not Moving with Given Range	A ÷ B
Vertical	Without Point	Record'd all	85	48.8	11.2	4.35
"	With Point	"	75	33.2	26.8	1.23
Horizontal	Without Point	"	68	41.25	18.75	2.2
"	With Point	"	64	27.3	32.7	0.83
Vertical	Without Point	4 mm.	30	13.0	47.0	0.28
"	With Point	"	25	5.1	54.9	0.09
Horizontal	Without Point	"	13	6.55	53.45	0.01
"	With Point	"	1	0.4	59.6	0.006
Vertical	Without Point	6 mm.	24	8.6	51.4	0.16
"	With Point	"	15	4.3	54.7	0.007
Horizontal	Without Point	"	9	4.75	54.25	0.008
"	With Point	"	0	0	120.0	

TABLE XV. (Observer B; time of obs., 1 min.)

Arrangement	Fixation	Range of Movement	No. of Movements of Given Range	A. Time Eye Moving with Given Range	B. Time not Moving with Given Range	A ÷ B
Vertical	Without Point	Record'd all	62	32.9	27.1	1.21
"	With Point	"	80	39.1	20.9	1.87
Horizontal	Without Point	"	40	28.8	31.2	0.92
"	With Point	"	56	31.6	28.4	1.11
Vertical	Without Point	2 mm.	16	13.5	46.5	1.29
"	With Point	"	26	19.6	40.4	0.40
Horizontal	Without Point	"	14	10.4	49.6	0.20
"	With Point	"	20	13.1	46.9	0.28
Vertical	Without Point	4 mm.	6	5.2	54.8	0.095
"	With Point	"	14	7.4	52.6	0.14
Horizontal	Without Point	"	2	3.1	56.9	0.054
"	With Point	"	10	5.3	54.7	0.96
Vertical	Without Point	7 mm.	0	0	60.0	
"	With Point	"	4	2.5	57.5	0.043
Horizontal	Without Point	"	0	0	0	
"	With Point	"	2	1	59.0	0.017

TABLE XVI. (Observer W; time of obs., 1 min.)

Arrangement	Fixation	Range of Movement	No. of Movements of given Range	A. Time eye moving with given Range	B. Time not moving with given Range	A ÷ B
Vertical	Without Point	Record'd all	55	40.43	19.5	2.07
"	With Point	"	46	13.67	46.32	0.29
Horizontal	Without Point	"	47	23.4	36.6	0.64
"	With Point	"	35	10.2	49.8	0.20
Vertical	Without Point	2 mm.	45	19.4	40.5	0.48
"	With Point	"	32	9.7	50.25	0.19
Horizontal	Without Point	"	39	14.5	45.5	0.31
"	With Point	"	28	8.27	51.72	0.16
Vertical	Without Point	4 mm.	21	12.2	47.75	0.25
"	With Point	"	16	4.22	57.75	0.07
Horizontal	Without Point	"	16	9.7	50.3	0.19
"	With Point	"	10	3.15	56.85	0.05
Vertical	Without Point	6 mm.	5	1.9	58.1	0.0024
"	With Point	"	3	1.15	58.85	0.0019
Horizontal	Without Point	"	3	1.05	58.95	0.0018
"	With Point	"	0	0	60.0	

TABLE XVII

Arrangement	Fixation	Range of Movement	No. of Movements of Given Range	A. Time eye moving with given Range	B. Time not moving with given Range	A ÷ B
Vertical	Without Point	Record'd all	28	39.4	20.6	1.91
"	With Point	"	18	22.8	37.2	0.61
Horizontal	Without Point	"	19	30.6	29.4	1.04
"	With Point	"	15	19.5	40.5	0.48
Vertical	Without Point	9 mm.	3	1.5	58.5	0.025
"	With Point	"	2	0.7	59.3	0.011
Horizontal	Without Point	"	2	0.9	59.1	0.015
"	With Point	"	0	0	60.0	

(2) The shift of the after-image from the stimulus was used to determine the eye-movement for each one of the fixation devices. The square of Hering blue paper, 3.5 by 3.5 cm., was observed in turn without a fixation point, with a fixation point placed at its centre, with a fixation point displaced from its centre so as to exaggerate the movement, and with a fixation point so displaced as to correct the movement. Thus frequency and total time of movement were taken account of. Only one table will be given to illustrate these determinations.

TABLE XVIII

W. Showing the effect upon eye-movement of the fixation devices used in Table X. Time of obs., 1 min.

Variation	Time Moving	Time Still	Time Moving ÷ Time Still
Without Fixation Point	27.9	32.0	0.87
With Fixation Point	15.3	44.7	0.34
Exaggerated	38.2	21.8	1.75
Corrected	7.9	53.1	0.15

(3) The eye-movement for each one of the fixation devices was also determined by the second method (second form). The after-image was obtained as in the after-image experiments; and the key was held down as long as the image was moving, and released while it was at rest.

TABLE XIX

A. Showing the effect upon eye-movement of the fixation devices used in Table VIII

Variation	Time Observed	Time Moving	Time Still	Time Moving ÷ Time Still	Rate of Movement [1]
Without fixation point	94.9	82.8	12.1	6.84	Moderate
With fixation point	118.0	85.1	32.9	2.58	Movem't slow. Correction jerky
Exaggerated	62.2	58.5	3.7	15.81	Very rapid
Corrected	125.7	68.9	56.8	1.21	Very slow

TABLE XX

B. Showing the effect upon eye-movement of the fixation devices used in Table IX

Variation	Time Observed	Time Moving	Time Still	Time Moving ÷ Time Still	Rate of Movement
With fixation point	112.5	32.0	80.5	0.39	Movem't slow. Correction jerky
Without fixation point	94.1	47.3	46.8	1.01	Moderate
Exaggerated	50.0	46.6	3.4	13.70	Very rapid
Corrected	159.7	14.7	145.0	0.10	Very slow

(3) *The form of the stimulus affects the frequency of fluctuation.* The stimulus was, as in the former experiments, of standard Hering blue. When squares were used, they were made so small that their edges lay within the field of direct observation; they could thus exert no influence to increase eye-movement, and we should expect a minimal disturbance of the after-image. The strips, on the other hand, were made

[1] The introspections as to rate of movement have not been incorporated in the other sets of eye-movement tables. In general, when the ratio 'time moving ÷ time still' is increased, the rate of movement is also increased.

TABLE XXI

M. Showing the effect upon eye-movement of the fixation devices used in Table XI

Variation	Time Observed	Time Moving	Time Still	Time Moving ÷ Time Still	Rate of Movement
Without fixation point	84.6	35.1	49.5	0.70	Moderate
With fixation point	100.4	8.3	92.1	0.09	Movem't slow. Correction jerky
Exaggerated	70.2	50.0	20.2	2.47	Very rapid
Corrected	139.0	0	139.0		Very slow

narrow, so that, as their areas were equal to those of the squares, their ends were thrown into the field of indirect observation, and the tendency was towards increased eye-movement. Thus maximal disturbance of fixation was obtained for the given area, and correspondingly a maximal disturbance of the after-image was expected.

To illustrate: a strip .5 x .5 cm. had, as its equivalent area, a square of 1.5 cm.; a strip .5 x 10 cm., a square of 2.2 cm.; a strip .5 x 20 cm., a square of 3.1 cm.; and a strip .5 x 40 cm., a square of 4.4 cm. Only the squares of 2.2, 3.1 and 4.4 cm. fluctuated at all, while the strips showed a rapid increase in fluctuation until .5 by 40 cm. was reached, when a slight decrease occurred. A strip .5 x 20 cm., *e. g.*, gave for A 8 fluctuations, with an average phase of visibility of 7.3 sec.; while its equivalent square gave no fluctuations at all (av. vis., 71.5 sec.). No record was taken of fluctuation in parts; only total disappearances were registered. Thus the actual disturbance suffered by the strip-image was taken account of only in part.

It may be deduced from the following tables that the shape of the curve of frequency obtained by increasing the length of the strips is somewhat different from that obtained by increasing the area of the squares (Tables II-IV). If a curve were plotted by laying off the lengths of the strips along the abscissa and the frequency of fluctuation along the ordinate, the curve would start on or near the abscissa, rise fairly steeply until a length of 20-40 cm. was reached, and then bend downward slightly. It would not reach the abscissa, since with the lengths of strip used fluctuation did not cease as it did with increase of area when squares were used. The reason of this difference between the results of the two sets of experiments will be given later, in our discussion of the streaming phenomenon.

TABLE XXII

A. Form of stimulus affects frequency of fluctuation of after-image. Results showing that fluctuation is more frequent when stimulus is in form of strip, than when it is in form of a square of equivalent area

Form	Area	No. of Fluctuations	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
Strip	.5 x 2 cm.	0	42.0	42.0	0	42	0	41.5
Strip	.5 x 5 cm.	2	26.0	14.0	1.0	43	2.0	44.5
Square	1.5 x 1.5 cm.	0	52.0	52.0	0	52	0	51.5
Strip	.5 x 10 cm.	6	35.0	8.0	1.2	56	7.3	63.4
Square	2.2 x 2.2 cm.	0	61.0	61.0	0	61	0	61.0
Strip	.5 x 20 cm.	8	26.5	7.3	1.6	66	13.4	79.8
Square	3.1 x 3.1 cm.	0	72.0	72.	0	73	0	71.5
Strip	.5 x 40 cm.	7	26.0	9.5	1.3	76	9.4	85.4
Square	4.4 x 4.4 cm.	3	59.5	19.0	2.0	73	6.0	79.0

TABLE XXIII. (Observer W.)

Form	Area	No. of Fluctuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. ÷ Invis.
Square	.5x .5cm.	0	37.2	37.2	37.2	0	0	37.2
Strip	.5x 5 "	2	14.7	15.7	47.2	2.0	4.0	51.2
Square	1.5x1.5 "	1	20.5	33.2	64.5	1.0	1.0	65.5
Strip	.5x 10 "	3	11.5	13.2	55.0	1.4	4.2	59.2
Square	2.2x2.2 "	1	43.0	34.0	68.0	2.5	2.5	70.5
Strip	.5x20 "	3	9.7	15.7	62.8	0.9	2.7	65.5
Square	3.1x3.1 "	2	29.5	23.15	69.5	1.5	3.0	72.5
Strip	.5x40 "	3	11.5	19.2	77.0	2.9	4.4	81.4
Square	4x4 "	2	23.0	24.5	73.5	1.3	3.9	77.4
Strip	.5x61 "	3	6.0	21.8	87.5	3.6	5.5	93.0

TABLE XXIV. (Observer M.)

Form	Area	No. of Fluct-uat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
Square	.5x .5 cm.	0	55.0	55.0	55.0	0	0	55.0
Strip	.5x 5 "	1	59.7	39.6	79.2	1.5	1.5	80.7
Square	1.5x1.5 "	0	66.4	66.4	66.4	0	0	66.4
Strip	.5x10 "	4	32.2	12.5	62.3	2.1	8.4	70.7
Square	2.2x2.2 "	1	58.5	33.0	66.0	4.0	4.0	70.0
Strip	.5x20 "	6	9.2	8.7	61.0	3.2	19.2	80.4
Square	3.1x3.1 "	1	97.0	50.5	101.0	1.0	1.0	101.0
Strip	.5x40 "	6	12.5	7.7	54.5	4.4	26.4	80.9
Square	4.4x4.4 "	2	93.0	32.5	97.5	7.1	14.2	111.7
Strip	1.5x50 "	4	20.5	10.2	51.0	3.9	15.6	66.6

The second method (second form) was here used for investigating eye-movement. The squares and strips were projected on a sheet of engine-gray cardboard, without a fixation point, and the times were recorded during which they were moving and at rest.

TABLE XXV

A. Eye-movement, with variation in form of stimulus. Showing that more involuntary eye-movement occurs during observation of after-image when stimulus is a strip than when it is a square of equivalent area.

Form of Stimulus	Dimensions of Stimulus	Time Ob-served	Time Moving	Time Still	Time Moving ÷ Time Still
Strip	.5 x 5 cm.	24.12	12.02	12.10	0.98
Square	1.5 x 1.5 cm.	35.45	9.40	26.05	0.36
Strip	.5 x 10 cm.	30.00	15.25	14.75	1.03
Square	2.2 x 2.2 cm.	46.80	16.35	30.50	0.53
Strip	.5 x 20 cm.	36.55	24.53	12.03	2.04
Square	3.1 x 3.1 cm.	50.07	19.98	30.72	0.65
Strip	.5 x 40 cm.	38.85	19.50	19.35	1.01
Square	4.4 x 4.4 cm.	55.80	25.50	30.30	0.84

TABLE XXVI. (Observer M.)

Form of Stimulus	Dimensions of Stimulus	Time Observed	Time Moving	Time Still	Time Mov'g ÷ Time Still
Strip	.5x 5 cm.	36.54	14.92	21.62	0.69
Square	1.5x1.5 "	46.90	8.80	38.10	0.23
Strip	.5x10 "	43.25	21.07	22.18	0.95
Square	2.2x2.2 "	49.20	13.30	35.90	0.37
Strip	.5x20 "	49.70	31.23	18.47	1.69
Square	3.1x3.1 "	52.30	19.20	33.10	0.58
Strip	.5x40 "	54.80	35.50	19.30	1.84
Square	4.4x4.4 "	57.90	24.70	33.20	0.74

TABLE XXVII. (Observer W.)

Form of Stimulus	Dimensions of Stimulus	Time Observed	Time Moving	Time Still	Time Mov'g ÷ Time Still
Square	.5x .5 cm.	63.0	15.35	47.65	0.32
Strip	.5x .5 "	64.5	26.20	38.80	0.68
Square	1.5x1.5 "	82.0	21.55	60.45	0.35
Strip	.5x10 "	73.5	33.90	39.60	0.86
Square	2.2x2.2 "	89.0	32.30	56.70	0.57
Strip	.5x20 "	82.0	38.90	42.10	0.90
Square	3.1x3.1 "	89.75	33.50	56.25	0.60
Strip	.5x40 "	97.5	48.25	49.25	0.98
Square	4.4x4.4 "	82.0	35.40	46.60	0.76

(4) *The arrangement of the stimulus with reference to the direction of greatest eye-movement affects the frequency of fluctuation and the duration of the after-image.* The stimuli for A were strips of Hering standard blue, .5 cm. wide and of various lengths; the stimuli for W were strips of 2 cm. wide. These were placed first in the vertical and then in the horizontal plane, and fixated at the centre for 40 sec. The images were observed on a background of engine-gray cardboard, with a fixation point. The tables show more frequent fluctuation, a shorter first phase of visibility, and a shorter total visibility, when the length of the strips is in the vertical plane. Correspondingly, the eye-movement tables show a greater range and frequency in the direction of the lesser dimension of the after-image (the horizontal plane). The results found with the

trained observers have been paralleled in laboratory practice. Those published from this latter class were obtained with Miss Stout (S), a student at Bryn Mawr College.

TABLE XXIX

A. The arrangement of stimulus with reference to direction of greatest eye-movement affects frequency of fluctuation and duration of after-image.

Arrangement of Strip	Dimensions of Strip	No. of Fluctuations	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
Vertical	.5 x 5 cm.	2	11.1	33.2	0.5	1.0	34.3
Horizontal	" "	0	47.5	47.5	0	0	47.5
Vertical	.5 x 10 cm.	5	4.0	24.0	0.9	4.5	29.5
Horizontal	" "	1	24.1	48.2	2.9	2.9	51.1
Vertical	.5 x 20 cm.	7	3.8	30.4	1.1	7.7	61.5
Horizontal	" "	1	29.3	58.6	2.9	2.9	38.1
Vertical	.5 x 40 cm.	6	8.7	60.9	0.8	4.8	65.7
Horizontal	" "	3	19.1	76.4	0.7	2.1	78.5

TABLE XXX. (Observer W.)

Arrangement	Area	No. of Fluctuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. ÷ Invis.
Vertical	2x5 cm.	2	13.0	16.4	49.2	1.5	3.0	52.2
Horizontal	2x5 "	2	16.5	21.8	65.4	1.6	3.2	68.6
Vertical	2x10 "	2	22.0	17.3	52.0	1.5	3.0	55.0
Horizontal	2x10 "	2	34.5	22.1	66.5	1.4	2.8	69.3
Vertical	2x20 "	3	24.5	16.6	66.5	2.0	6.0	72.5
Horizontal	2x20 "	3	37.0	21.8	87.2	1.3	3.9	91.1
Vertical	2x40 "	4	22.0	16.6	84.0	1.6	6.4	90.4
Horizontal	2x40 "	3	27.6	22.0	88.0	1.4	4.2	92.2
Vertical	2x50 "	3	12.0	16.7	66.8	0.9	3.6	70.4
Horizontal	2x50 "	3	19.5	20.5	82.0	0.7	2.8	84.8

The eye-movement records of A and W, in the horizontal and vertical planes, are given in Tables XIV, XVI. In both cases, for every point recorded, there was marked excess in the horizontal plane. Owing to lack of time this determination was not made for S. The fact, however, that in S's duplication series the eye-movement across the strip was always more

TABLE XXXI. (Observer S.)

Arrangement of Strip	Dimensions of Strip	No. of Fluctuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. ÷ Invis.
Vertical	.5x 5 cm.	2	14.2	9.6	28.8	2.6	5.2	34.0
Horizontal	.5x 5 "	1	32.0	17.4	34.8	4.0	4.0	38.8
Vertical	.5x10 "	3	12.6	7.5	30.0	2.1	6.3	36.3
Horizontal	.5x10 "	2	28.9	13.6	40.8	3.5	10.5	51.3
Vertical	.5x20 "	8	10.4	5.6	50.4	1.5	12.0	62.4
Horizontal	.5x20 "	4	27.2	13.3	65.5	2.4	9.6	75.1
Vertical	.5x40 "	5	24.5	9.8	58.8	4.0	20.0	78.8
Horizontal	.5x40 "	3	30.4	16.4	65.6	4.6	13.8	79.4

effective for fluctuation than that along it indicates that the greater frequency of fluctuation when the strip was arranged vertically was due to an excess of eye-movement in the horizontal plane.

(5) *The results in (1), (3) and (4) can be roughly duplicated by using voluntary eye-movement to cause the disappearances.* The voluntary eye-movement was regulated throughout in the following manner. The after-image was observed with the aid of a fixation point. A second point was placed 12 cm. to the right of this. At a signal, given every 3 sec. by the experimenter, the observer moved his eyes quickly out to this point and back again. He was told to record as a 'disappearance' only a case in which the after-image failed to reappear after the eyes had regained their normal fixation. Thus nothing but genuine disappearances were taken account of. Possible visual synæsthesia attending eye-movement, distraction, etc., were guarded against by the directions under which the observer worked. The after-images were blotted out as completely as after-images ever are in the case of natural fluctuation. There is not a shadow of doubt on this point. The more uniform side of engine-gray cardboard was used as background for both stimulus and after-image. Hence there was no danger of disturbance by possible distractions due to movement of the eye over an irregularly marked surface.

i. Fluctuation occurs only within a limited range of areas. Just as when the observation is made under the conditions of ordinary fixation, the after-effect of general adaptation does not fluctuate under the influence of voluntary eye-movement. Nor do after-images fluctuate beyond a comparatively limited range of areas. Within this range the results are very similar to those obtained in the case of natural fluctuation. Large images do not fluctuate at all; small images little, if at all;

while middle-sized images alone fluctuate readily. The curve of frequency takes the same general shape as it does with natural fluctuation.

TABLE XXXII

A. Duplication of results by voluntary eye-movement. Method of variation of area.

Area	No. of Fluct-uat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
.5x .5 cm.	0	35.5	35.5	35.5	0	0	35.5
1.5x1.5 "	1	54.5	30.0	60.0	0.6	0.6	60.6
5x5 "	3	59.0	18.2	72.8	1.5	4.5	77.3
10x10 "	13	23.2	6.5	91.0	0.7	9.1	100.1
20x20 "	12	32.0	6.2	80.6	0.6	7.2	87.8
40x40 "	2	78.5	30.5	91.5	0.9	1.8	93.3
61x50 "	0	89.7	89.7	89.7	0	0	89.7

TABLE XXXIII. (Observer W.)

Area	No. of Fluct-uat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. ÷ Invis.
.5 x .5 cm.	0	33.0	33.0	33.0	0	0	33.0
1 x 1 "	3	26.2	10.0	40.2	0.55	1.7	41.9
5 x 5 "	7	11.5	5.2	43.3	0.75	5.3	48.6
10 x 10 "	14	19.4	5.0	75.9	0.6	7.9	83.8
20 x 20 "	13	20.2	3.7	52.0	1.6	21.1	73.1
40 x 40 "	0	82.0	82.0	82.0			82.0
61 x 50 "	0	69.5	69.5	69.5			69.5

TABLE XXXIV. (Observer M.)

Area	No. of Fluct-uat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
.5x .5 cm.	0	47.0	47.0	47.0	0	0	47.0
1.5x1.5 "	0	71.0	71.0	71.0	0	0	71.0
10x10 "	11	54.5	6.5	82.5	2.0	22.8	105.3
20x20 "	11	31.5	5.2	63.1	1.5	17.1	80.2
40x40 "	10	37.0	5.4	60.0	1.3	13.6	73.6
61x50 "	0	46.0	46.0	46.0	0	0	46.0

ii. The form of the stimulus affects the frequency of fluctuation. The same set of stimuli were used as for natural fluctuation, and all the other conditions of the experiment were kept as nearly as possible the same. It will be observed that here, as before, the squares fluctuated little, if at all, while the strips increase in frequency of fluctuation with increase of length until a certain point is reached, when a slight decrease takes place.

TABLE XXXV

A. Duplication of results by voluntary eye-movement. Results showing that fluctuation is more frequent when stimulus is a strip than when it is a square of equivalent area.

Form	Area.	No. of Fluc-tuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. ÷ Invis.
Strip	.5 x 2 cm.	0	38.5	38.5	38.5	0	0	38.5
Strip	.5 x 5 "	3	6.2	12.5	50.0	4.0	1.2	51.2
Square	1.5 x 1.5 "	0	49.0	49.0	49.0	0	0	49.0
Strip	.5 x 10 "	4	3.3	8.5	42.5	0.3	1.2	43.7
Square	2.2 x 2.2 "	0	56.0	56.0	56.0	0	0	56.0
Strip	.5 x 20 "	7	2.5	7.6	60.8	0.35	2.2	63.0
Square	3.1 x 3.1 "	1	67.0	35.8	71.6	1.9	1.9	73.5
Strip	.5 x 40 "	5	4.5	11.1	66.6	0.39	1.9	68.5
Square	4.4 x 4.4 "	2	66.0	24.5	73.5	1.1	2.2	75.7

TABLE XXXVI. (Observer W.)

Form	Area	No. of Fluct-uat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
Square	.5x .5 cm.	0	40.5	40.5	40.5	0	0	40.5
Strip	.5x5 "	3	23.5	18.5	74.0	1.2	3.6	77.6
Square	1.5x1.5 "	1	38.5	31.3	62.6	1	1	63.6
Strip	.5x10 "	4	14.0	13.7	68.5	1.9	5.7	74.2
Square	2.2x2.2 "	1	32.6	28.2	56.4	1.5	3	59.4
Strip	.5x20 "	4	16.9	14.0	70.0	1.5	6.0	76.0
Square	3.1x3.1 "	2	29.4	26.3	78.9	1.2	2.4	81.3
Strip	.5x40 "	3	23.0	21.1	84.4	1.8	5.4	89. 3
Square	4.4x4.4 "	3	26.2	23	92	1.3	3.9	95.9

TABLE XXXVII. (Observer M.)

Form	Area	No. of Fluct-uat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
Square	.5x .5 cm.	0	48.3	48.3	68.3	0	0	68.0
Strip	.5x5 "	5	56.0	12.6	75.6	1.0	5.0	80.6
Square	1.5x1.5 "	0	68.2	68.2	68.2	0	0	68.2
Strip	.5x10 "	9	36.6	6.7	67.0	1.2	10.8	77.8
Square	2.2x2.2 "	2	55.6	23.3	69.9	2.0	4.0	73.9
Strip	.5x20 "	11	11.4	5.4	64.8	1.1	12.1	76.9
Square	3.1x3.1 "	3	82.6	26.0	104.0	2.4	7.2	111.2
Strip	.5x40 "	11	11.9	5.2	62.4	1.2	13.2	75.6
Square	4.4x4.4 "	4	86.6	19.6	98.0	2.4	9.6	107.6

iii. The arrangement of the stimulus with reference to the direction of greatest eye-movement influences the frequency of fluctuation and the duration of the after-image. Again, the same set of stimuli were used as for natural fluctuation, and the other conditions of the experiment were kept the same. For W the eye-movement was given in the horizontal plane with both arrangements of the stimuli. The tables show that when the strip was arranged with its length in the vertical plane, so that the movement was directed along its shorter dimension, the fluctuations were more frequent and the duration was shorter.

TABLE XXXVIII

W. Duplication of results by voluntary eye-movement. Showing that the arrangement of the stimulus with reference to the direction of greatest eye-movement affects the frequency of fluctuation and the duration of the after-image.

Arrangement	Area	No. of Fluct-uat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. ÷ Invis.
Vertical	2 x 5 cm.	2	12.9	11.1	33.3	0.7	1.4	34.7
Horizontal	2 x 5 "	2	17.4	16.6	49.8	1.1	2.2	52.0
Vertical	2 x 10 "	3	22.8	10.2	40.8	0.8	2.4	43.2
Horizontal	2 x 10 "	3	33.6	15.4	61.6	1.0	3.0	64.6
Vertical	2 x 20 "	4	25.5	8.9	44.5	0.7	2.8	47.3
Horizontal	2 x 20 "	4	39.0	13.2	66.0	0.9	3.6	69.6
Vertical	2 x 40 "	5	22.4	9.2	55.2	0.8	4.0	59.2
Horizontal	2 x 40 "	5	38.6	15.0	90.0	1.2	6.0	9.6
Vertical	2 x 50 "	5	18.2	8.7	52.2	1.1	5.5	57.7
Horizontal	2 x 50 "	4	26.3	14.8	74.0	1.3	5.2	79.2

The law that eye-movement, when directed along the lesser dimension of the after-image, is more effective to produce fluctuation and to shorten duration was given a still more thorough verification in the cases of A and S. The strip was

TABLE XXXIX. (Observer A.)

Arrangement of Strip	Dimensions of Strip	Direction of Movement	No. of Fluct-uat's	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
Horizontal	.5x10 cm.	Vertical	4	3.3	16.5	0.8	3.2	19.7
"	"	Horizontal	3	14.8	59.2	0.9	2.7	61.9
Vertical	"	Horizontal	5	5.8	34.8	0.5	2.5	37.3
"	"	Vertical	1	22.0	44.0	1.4	1.4	45.4
Horizontal	.5x20 cm.	Vertical	8	5.1	45.9	0.6	4.8	50.7
"	"	Horizontal	1	25.0	50.0	0.5	0.5	50.5
Vertical	"	Horizontal	6	3.2	22.4	0.6	3.6	26.0
"	"	Vertical	2	16.4	49.2	1.1	2.2	51.4
Horizontal	.5x40 cm.	Vertical	3	13.2	52.8	0.4	1.2	54.0
"	"	Horizontal	1	34.7	69.4	0.3	0.3	69.7
Vertical	"	Horizontal	6	4.0	28.0	0.4	2.4	30.4
"	"	Vertical	4	10.1	50.5	0.5	2.0	52.5

placed with its length in the horizontal plane, and eye-movement prescribed first in the vertical and then in the horizontal plane. Then the strip was placed with its length in the vertical plane, and movement prescribed first in the horizontal and then in the vertical plane. It is thus shown that the law is not dependent upon the plane in which the strip is arranged, or the direction of the eye-movement, but that the only essential condition is that the movement be along the lesser dimension of the after-image.

TABLE XL. (Observer S.)

Arrangement of Strip	Dimensions of Strip	Direction of Movement	No. of Fluctuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. ÷ Invis.
Vertical	.5 x 10cm.	Horizontal	5	21	5.9	35.4	2.6	13.0	48.4
"	.5 x 10 "	Vertical	2	30	14.3	42.9	3.2	6.4	49.3
Horizontal	.5 x 10 "	"	4	34	9.0	45.0	2.0	8.0	53.0
"	.5 x 10 "	Horizontal	3	42	13.7	54.8	3.3	9.9	64.7
Vertical	.5 x 20 "	"	16	19	4.1	69.7	2.0	32.0	101.7
"	.5 x 20 "	Vertical	9	43	7.9	79.0	2.7	24.3	103.3
Horizontal	.5 x 20 "	"	8	35	7.3	65.7	1.7	13.6	79.3
"	.5 x 20 "	Horizontal	6	58	11.5	80.5	2.7	16.2	96.7
Vertical	.5 x 40 "	"	8	45	8.7	78.3	2.6	20.8	99.1
"	.5 x 40 "	Vertical	5	56	14.1	84.6	3.1	15.5	100.1
Horizontal	.5 x 40 "	"	6	63	13.3	93.1	2.0	12.0	105.1
"	.5 x 40 "	Horizontal	4	78	20.0	100.0	2.3	9.2	109.2

(6) *An increase in the time of stimulation increases the number of fluctuations of the after-image.* Hering standard blue, 10 by 10 cm., was used as stimulus for A and M; the same

TABLE XLI

A. Increase of time of stimulation increases frequency of fluctuation of after-image.

Time of Stimulation	No. of Fluctuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. ÷ Invis.
10 sec.	1	42.0	27.5	55	5.4	5.4	60.4
40 "	4	78.4	23.8	119	3.1	12.4	131.4
70 "	7	97.6	20.2	162	2.4	16.8	178.8
90 "	8	94.3	17.4	157	2.1	16.8	173.8

blue, 5 by 5 cm., was used for W. The stimulus was placed on a square of engine-gray cardboard, and fixated at its centre. The after-image was projected upon a similar cardboard, with a fixation point.

It will be noticed that, with a stimulation of 10 sec., the after-image began fluctuating 8.4 sec. before its final disappearance; with 40 sec., 53 sec. before; with 70 sec., 81.2 sec. before; and with 90 sec., 87.5 sec. before disappearance. Increase in the time of stimulation results, then, in the after-image beginning to fluctuate at a greater intensity. If this result is taken in connection with the proof of an increase of eye-movement for the longer times of stimulation, it affords a strong indication that eye-movement causes fluctuation. The conclusion is made almost positive by the fact that increase of intensity, without increase of time of stimulatiom, does not increase fluctuation.

TABLE XLII. (Observer W.)

Time of Stimulation	No. of Fluctuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. + Invis.
10 sec.	0	23.9	23.9	23.9	0	0	23.9
40 "	2	13.3	19.3	38.7	1.7	3.4	42.1
70 "	3	22.1	16.8	64.4	1.7	5.1	69.5

The table shows that with a stimulation of 10 sec. the after-image did not fluctuate at all; with 40 sec. it began to fluctuate 28.8 sec., and with 70 sec., 47.4 sec. before final disappearance.

TABLE XLIII. (Observer M.)

Time of Stimulation	No. of Fluctuat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. ÷ Invis.
10 sec.	0	18.0	18.0	18.0	0	0	18.0
40 "	4	42.0	10.7	53.5	3.0	12.0	65.5
100 "	6	48.0	9.8	68.8	3.2	19.0	87.8

An inspection of the table will show that with a stimulation of 10 sec., the after-image did not fluctuate at all; with 40 sec., it began to fluctuate 23.5 sec., and with 100 sec. 39.8 sec. before it finally disappeared.

That increase in eye-movement follows increase in the time of stimulation was proved by the second method for the investi-

gation of eye-movement: *i. e.*, by a direct record of the movement of the projected after-image. The following results were obtained.

TABLE XLIV

A. Eye-movement with variation in time of stimulation. Showing that increase in time of stimulation increases the involuntary eye-movement occurring when after-image is observed.

Time of Stimulation	Time Observed	Time Moving	Time Still	Time Moving ÷ Time Still
10 sec.	14.7	4.95	9.75	0.5
70 "	54.5	26.4	28.1	0.94
100 "	41.0	23.0	18.0	1.28
130 "	52.2	30.4	22.3	1.36
180 "	46.0	24.4	21.65	1.12

TABLE XLV. (Observer W.)

Time of Stimulation	Time Observed	Time Moving	Time Still	Time Moving ÷ Time Still
10 sec.	64.35	22.75	41.6	0.54
40 "	85.0	29.0	46.0	0.85
70 "	96.5	48.35	48.2	1.0
130 "	102.0	55.3	46.7	1.16
190 "	95.0	59.85	35.15	1.7

TABLE XLVI. (Observer M.)

Time of Stimulation	Time Observed	Time Moving	Time Still	Time Moving ÷ Time Still
10 sec.	22.5	3.25	19.25	0.11
40 "	61.0	25.75	35.25	0.73
70 "	52.4	29.65	22.75	1.30

It was stated under the heading 'Results: General' that increase in the time of stimulation gave three results: it increased

the intensity of the after-image, the amount of involuntary eye-movement, and both the number of fluctuations and the intensity at which fluctuation began. In order to determine positively which of the two first is the cause of the third, it was necessary to study the effect of increase of intensity in isolation, *i. e.*, to increase intensity without increase of involuntary eye-movement. Since increase in involuntary eye-movement is found to follow increase in time of stimulation, the increased intensity must be secured without increase of stimulation time. This was done as follows: Hering-gray, no. 31, was used as stimulus background. Squares 5 by 5 cm. of Hering grays 15 and 7, and of Hering white, were used in turn as stimuli. The intensity of the stimulus in this case is measured by its difference from the background. Thus the intensities, roughly at least, stood in the relation 16 : 24 : 31. A square of Hering gray no. 15 was used as the background upon which to project the after-images. This shade of gray was selected because it corresponded approximately to the after-effect of the stimulus background. Thus the projection background was kept constant until the after-image, whose fluctuations were being observed, finally disappeared. This precaution may not have been necessary, but it seemed well to plan the experiment as carefully as possible. The time of stimulation was 40 sec. throughout. All these conditions were the same for the different stimuli.

A typical set of averages has been selected for publication. It will be observed that increase of intensity, without increase in time of stimulation, does not increase either the number of fluctuations, or the intensity at which fluctuation begins. Hence these results, when obtained with increase in time of stimulation, must be due to increase of eye-movement.

TABLE XLVII

A. Results showing that increase in intensity does not increase fluctuation of after-image.

Stimulus	No. of Fluct-uat's	1st Vis.	Av. Vis.	Total Vis.	Av. Invis.	Total Invis.	Vis. ÷ Invis.
Hering Gray No. 15 on " " " 31	5	20.3	7.4	44.4	2.7	13.5	57.9
Hering Gray No. 7 on " " " 31	5	22.0	9.3	55.8	1.9	9.5	65.3
Hering White on " Gray No. 31	3	28.0	15.6	62.4	2.3	6.9	69.3

(7) *The observers most sensitive to the methods used to disturb fixation show the widest range of variability in fluctuation and duration.* This will be seen by a comparison of the eye-movement with the after-image tables for each of the observers and for the various methods used. Dr. Bair (B) and Miss Alden (A) were the most sensitive; the Misses Montgomery (M) and Wright (Wr) the least; and Miss Walter (W) was of intermediate sensitivity.

(8) *Increase of practice in fixation brought with it a decrease in the frequency of fluctuation and an increase in the duration of the after-image.* Space does not permit us to show in detail this falling off in sensitivity of the different observers as the work progressed. It will be sufficient to say that it was quite marked.

iii. *How does eye-movement cause the fluctuation and shorten the duration of the after-image?*

a. It is evident that neither Fechner's nor Helmholtz' theory is adequate to the results given in the preceding Sections. Changes in illumination (Helmholtz) do not account for the shape of the curve of frequency for variation of area. Nor do they explain the fluctuation of the after-image in parts, or the effect produced upon fluctuation by variations in the form and arrangement of the stimulus. Fechner's theory, that eye-movement arouses vascular and nervous disturbances which in turn react upon the after-image, is, first of all, too indefinite. We are not told how these disturbances work, and no tangible evidence is adduced that eye-movement produces them. In the second place, even if the disturbances are granted, it is difficult to understand why they take place in this and that part of the retina while the remainder is not affected (fluctuation in parts); why they are effective in the case of certain areas, and not at all in that of others (effect of variation of area on fluctuation); and, still more, why the form of the stimulus, and its arrangement with regard to the direction of greatest range and frequency of eye-movement, etc., affect the fluctuation and duration of the after-image as powerfully as they are found to do.

Fick and Gürber follow a different course. They study the relief of adaptation not, like Helmholtz and Fechner, from the side of the negative after-image, but from the positive side. They show in various ways that the color or brightness of a stimulus to which the eye has been adapted is restored by eye-movement. They contend that adaptation is a phenomenon of fatigue, and that eye-movement relieves it, chiefly, by facilitating the removal of the fatigue products from the retina; less importantly, by increasing the delivery of new material to the

fatigued end-organs. This hypothesis, though perhaps the most promising of all the eye-movement theories, is at the same time scarcely less speculative than the others. The passage of lymph to and from the retinal elements is a necessary postulate of metabolism; but Fick and Gürber give no direct or positive proof that eye-movement facilitates the exchange; nor has the proof been brought by any subsequent investigator.

Vascular disturbances in the retina are alleged as *indirect* evidence. The following authorities may be cited upon this point. On the negative side, we find A. Coccius (Ueber die Anwendung des Augenspiegels, etc., 1853, 20), who was the first to investigate the matter, asserting that the disturbances are not present in the case of quick, short eye-movements. O. Becker (Archiv f. Ophthalmol., XVIII, 1, 1872, 242) contends that eye-movement exerts no especial influence, since he finds fluctuations in the caliber of the retinal vessels when the eye-muscles are paralyzed by atropine. On the positive side, A. v. Graefe (Archiv f. Opthalmol., I, 2, 1855, 387) establishes the general principle that eye-movement causes an increase of pressure in the vitreous humor; hence every change of fixation is followed by an increase of vascular pulsation in the retina. Michell (Lehrbuch der Augenheilkunde, 1. Aufl., 547) observed that eye-movement causes a paling of the retinal capillaries. W. Dobrowolsky (Centralblatt f. d. medic. Wissensch., 1870, 20 and 21), working on a dog, observed frequent changes in the calibre of the retinal capillaries. These changes disappeared, however, when motor paralysis was produced by curare; the capillaries also became paler when the eye-muscles were electrically stimulated. Fick and Gürber themselves, working both on the human eye and on the eyes of dogs, were able in some cases to observe the effect of eye-movement on the calibre of the retinal vessels. They found, *e. g.*, in the case of the human eye, that when the eyes are held steadily upon some distant object, vascular changes are not noticeable, but that noticeable changes occur when the eyes are moved. They believe that these changes are not normal pulsations due to the heart's action, but are directly caused by the eye-movements. The natural pulse, they say, is not observable for various reasons: thus, it may possibly be obscured by the rapidity of the heart's action. This supposition seems to receive confirmation from the results of experiments on dogs. When the dogs were put under the influence of chloral or morphine, and all the eye-muscles severed, a rhythmical change in the calibre of the retinal vessels was plainly noticeable. Since eye-movement could not operate to produce this rhythm, they regard it as that of the natural retinal pulse, now rendered observable through the slowing of the heart's action by the drugs used. On the whole, however, and having regard both to their own work and to that of others, Fick and Gürber did not consider the evidence that eye-movement influences retinal circulation to be entirely satisfactory.

Moreover, if we look at the problem from the side of the negative after-image, the hypothesis can apparently be of service only in explaining the effect of eye-movement upon the total duration of the after-image. Facilitation of the removal of fatigue products does not account for fluctuation; for if the fatigue material is carried away so completely as to cause the disappearance of the after-image, there is no satisfactory or plausible reason why it should accumulate again, and cause the

after-image to reappear, when the eye has in the meantime undergone no additional stimulation.[1] Since, then, the hypothesis cannot explain a simple case of fluctuation, it manifestly cannot account for the variations in the phenomenon discussed in the foregoing pages;[2] and, failing in this regard, it manifestly has not taken into consideration all the factors that operate to relieve adaptation.

b. Much to our surprise, the solution of the problem came with the observation of a phenomenon which, for want of a better term, will be called the 'streaming phenomenon.' We turn to its consideration with the reluctance that a writer must feel in pointing out a new phenomenon in a field so old and so minutely canvassed as that of vision, but nevertheless with a full sense of responsibility. The phenomenon was first observed in 1905, and since that time has been carefully investigated by the writer with the aid of nine observers: seven students of psychology and two laymen. All were sceptical at the outset; but later, independently of one anothers' and of the writer's observations, were able to describe the phenomenon in detail, and to sketch the more prominent of the multitude of stream patterns.

1. A brief description is difficult. When one sits with lightly closed lids, which must be kept from quivering, before a bright diffuse light, such as that of a partly clouded sky,

[1] Fick and Gürber do not treat their problem from the side of the negative after-image, nor are they primarily concerned with this aspect of adaptation (especially with the fluctuation of the negative after-image); at the same time, they offer an explanation of this fluctuation. The explanation, however, does not account for the various cases and types of fluctuation; and its basis is both hypothetical and, in terms of the results of our own observers, contrary to fact. It runs as follows: "Augenbewegungen und Accommodation quetschen die Netzhaut gleichsam aus, das negative Nachbild verschwindet. Aber nicht aus der ganzen Netzhaut werden die Stoffwechselproducte entfernt, sondern nur aus der empfindlichsten Schichte; darum taucht das negative Nachbild in demselben Masse wieder auf, in dem sich die Stoffwechselproducte wieder über die empfindlichste Netzhautschichte verbreiten" (Archiv f. Ophthalmol., XXXVI, 300). Observation shows rather that instead of the waste material being forced from the after-image area by eye-movement, and returning to it when the intra-ocular pressure is relieved, just the reverse movement of material takes place. That is, eye-movement causes a wash of material from some part of the surrounding retina over the after-image area. As long as this streaming material is passing over the area, the after-image cannot be seen. When it has passed beyond it, the image reappears.

[2] It is not clear, *e. g.*, why the waste material forced from the after-image area does not return, to cause the reappearance of large and small after-images, as it does so readily in the case of after-images of medium area. Similar difficulties, too obvious to need separate mention, are encountered in the other cases discussed above.

and looks deep into the field of vision thus presented, beyond the background as usually observed, one sees about the point of regard, after the field of vision has steadied, slowly moving swirls.[1] These swirls have the appearance of streams of granules moving in broad curves now this way, now that, seemingly without order unless a noticeable eye-movement occurs, or is made voluntarily, when the direction of streaming changes to that of the eye-movement.[2] The change of direction is always on a curve, the abruptness of which depends upon the vigor of the movements, much as would happen if motions in different directions and of different magnitudes were compounded at intervals upon a fluid of considerable inertia. The phenomenon is extremely varied. Sometimes the central portion of the field of vision resembles the surface of a liquid about to boil, channeled this way and that by convection cur-

[1] The manner in which the lids are held is of extreme importance. They must not be closed so tightly that pressure is exerted on the eyeballs, and on the other hand, they must not admit light. It is difficult at first to find just the right background and the proper illumination. Quivering of the lids is fatal to the observation. The writer's only failure to secure a successful observation was on the part of an observer who could not keep the lids from trembling. Such painstaking precautions are necessary, however, only until the observer has once seen the phenomenon. Afterwards there is no difficulty. In fact, like the entoptic and circulation phenomena, the streaming may even become troublesome by its insistence. The plane of fixation is a matter of peculiar consequence. One must look through and beyond the shifting, changing, indefinite haze that occupies the visual foreground of the closed eyes. No better direction can be given than that the observer try to resolve this haze, to find out what lies in and behind it. He must gaze intently and penetratingly. Since the smoothest part of the closed lid lies above the centre of the eye, it is of advantage to look slightly upward, instead of directly forward. The steady field of vision should reveal the streaming, but voluntary eye-movement, by increasing its activity, frequently facilitates the observation. If one moves the eye sharply, and intently watches the field of vision in the trail of the movement, one sees (sometimes immediately following and sometimes lagging behind) a stream which takes the general direction of the movement. By way of final caution, we cannot emphasize too thoroughly the need of persistence and patience in observing. An unpractised observer should not expect to see the phenomenon in less than 2-5 minutes after closing his eyes. The field of vision must clear and settle, and the observer must grow accustomed to the unusual conditions of observation.

[2] The real movement of the streaming is in the opposite direction to that of the retina. The apparent motion of the eye is the movement of its anterior portion. This is opposite to the movement of the retina; hence the streaming material seems to pass across the field of vision in the direction in which the eye is moving. It might, of course, be expected that a mobile material on the retina would move under the influence of eye-movement as the streaming material is thus found to do.

rents moving at varying rates of speed. Now and again a heavy stream will sweep across this channeled surface from one direction or another, taking up the minor swirls as sharply curving tributaries, and so on, through manifold changes. Various patterns can be picked out, and a particular swirl may be traced in its deviations for a time; but, as a whole, the phenomenon cannot be adequately described.

After practice on the closed lids, the observers became able to trace the streaming on any dull or rough surface with the eyes open. It may also be observed under the conditions of observation of the entoptic and circulation phenomena; but just as one must look beyond the false scotomata to see the moving corpuscles and interspaces, so must one look beyond them to see the streaming. So competent did certain observers become, with the eyes open, that records were made in the experiments with minimal stimuli of the time that heavy streaming lasted during the phases of invisibility.[1]

2. In casting about for a physiological explanation of the streaming phenomenon, we have been led to believe that it is caused by a streaming over the retina of some material which is capable of directly affecting the processes that condition visual sensation. First, on the negative side, we find that it cannot be a circulation, entoptic, or tear-film phenomenon, or any of the shadow phenomena; for it is seen in the dark as well as in the light. In fact the best way to observe it, with the eyes open, is in the dark room or in a carefully muffled blackness cylinder. Secondly, on the positive side, we have three facts to consider. The streaming occurs, as we have just mentioned, in the dark as well as in the light. It is seen in the dark as a streaming and swirling of the intermingled blackness and luminous haze that compose the visual field. Here it must directly excite the black-white process. Again, the streams carry with them the quality of the background from which they proceed. This fact may be demonstrated as follows. Get upon the retina a large square blue after-image, having through its centre a vertical strip of yellow. Projected upon the field of vision afforded by the closed lids in daylight, this image will be seen as a strip of reddish yellow on a background of purple. A heavy stream, in passing across the strip, will sweep the purple with it across the yellow, and will deposit traces of the yellow in irregular patches on the further side. In other cases, where a heavy swirling takes place over the strip area, the yellow will break up irregularly, traces and

[1] The phenomenon comes out with remarkable clearness with open eyes, in the blackness of the dark room. The field of slightly luminous haze that there confronts one for some minutes, at a certain distance, streams and swirls with convincing distinctness.

patches of its color being borne out in different directions, and the background swept in. In yet other cases, the swirl will form outside the image, and sweep across it, much as a swirl of snow is carried before the wind. In all of these variations of stream-type, however, it is the unfailing rule that the quality of the background is carried by the stream from point to point in its course. Lastly, the streaming has a characteristic effect upon the after-image. Gentle streaming dims the after-image, apparently in proportion to its vigor, provided that it comes from an area of different visual quality, but heavy streaming blots it out absolutely. This occurrence, once seen, can never be doubted. The observation is positive.

3. The effect of streaming is the same, whether the eyes are open or closed. It is true that the stream is not so clearly seen to sweep over the after-image when this is projected on a background with the eyes open, as when it is projected on the field of the closed lids. Nevertheless, the instant that the image disappears, streaming can always be plainly seen over the area which it occupied. If the background is a rough, dull surface, the stream can even be seen to form and pass across the image. Most of our observers readily noticed this phenomenon, and some reported it before they had discovered streaming in the field of the closed lids, so that it formed their first observation of streaming.[1]

We have, further, indirect evidence of the identity of fluctuation under the two conditions of projection, in the striking

[1] A word of explanation here may prevent misunderstanding. What was observed, with the eyes open, was that the background seemed to sweep over this or that part of the after-image area, and that as the stream advanced the color disappeared. The stream seemed, decidedly, to sweep the color out, or at least to be causally connected with its disappearance. The phenomenon is, naturally, less striking than it is when the after-image is seen on the field of the closed lids. For one thing, the image is now projected on a field some distance away; the streams are thus magnified, and accordingly rendered vague and diffuse, less distinct in form and outline. For another thing, the brightness of daylight illumination tends to obscure the phenomenon. And other factors in the result could probably be mentioned.

Many of the brief disappearances of visual stimuli, especially those of positive stimuli of considerable intensity, are seen to be caused in the same way by streaming. The stream sweeps over them and blots them out; as it passes off, they reappear from behind, slightly farther back. The latter phenomenon is especially noticeable in the case of the shadows cast by a false scotoma on the retina.

Similar observations may be made in the course of adaptation experiments. Lay, *e. g.*, a fairly dark disc of Hering gray on a background of Hering gray several shades darker. While the disc is leveling down to the background, this or that portion of it will be repeatedly swept out by streams, moving across it in a curve. Many of the writer's laboratory students at different colleges have reported this phenomenon.

correspondence which obtains between the types of disappearance when the image is observed, as is ordinarily done, on a cardboard or other background, and when it is traced on the field of the closed lids in conjunction with streaming. Parallel series of experiments were carried out with after-images in the form of strips, squares, and crosses, large and small, projected both upon a background of cardboard and upon the field of the closed lids. The result was that, if a sufficient number of cases is considered, every type of disappearance found in the one series can be found also in the other. The following paired observations, selected at random, will illustrate this correspondence.

Stimulus: Milton Bradley standard yellow, 42 by 4 cm. After-image observed on background of engine-gray cardboard. Time of stimulation 30 sec. Distance of *O* 1 meter.

After-image dimmed over its whole area. Revived. Bottom went out. Reappeared. Whole image went, disappearing first along right edge in form of a curve, convex inwardly, then spreading. Reappeared, beginning along right edge. Top disappeared. Reappeared almost immediately. Top and bottom went out almost simultaneously, slowly followed by centre. (These disappearances rarely if ever occurred over the whole area at once. They began in a certain part, and then extended; one could see the area in process of being swept over. The parts disappearing were always bounded by curved lines.) Bottom came back first. Upper part disappeared, central and lower part dimmed, but did not disappear. Reappeared. Centre went out; then bottom. Quickly reappeared. Whole after-image disappeared, beginning in lower right-hand corner and spreading towards the top. Faintly reappeared. Vanished.

Stimulus: Milton-Bradley standard yellow, 42 by 4 cm. After-image observed on the field of the closed lids. Time of stimulation, 30 sec. Distance of *O* 1 meter.

Gentle streaming aud dimming over the whole area of the after-image. Upper half and centre swept out by a swirl moving counter clockwise, and carried across from the left. Reappeared. Whole after-image blotted out by two streams moving from left and right, joining, and moving upwards for the whole length of the after-image. Cleared over whole area, beginniug at bottom. Lower part swept out by a stream moving obliquely down and to left. Almost immediately another swept up and to right, carrying out centre and upper half. Reappeared. Swirl counter-clockwise cut off top. Reappeared. Stream moving on a very gradual curve to right from above cut out all but right edge of lower half. Finally this became involved. Cleared. Heavy stream moved across centre from right, blotting it out; divided and swept back on itself obliquely towards top and bottom, carrying out whole after-image. General commotion. Dimmed. Unable to follow changes farther.

Stimulus: Milton-Bradley yellow, 10 by 10 cm. After-image observed on engine-gray cardboard. Time of stimulation, 30 sec. Distance of *O* 1 meter.

Gradually dimmed. A curved segment was blotted out of left side. Reappeared. Disappeared, beginning with top. Reappeared, beginning with upper right-hand corner. Disappeared, beginning with top and upper left corner. Left side came back first, then whole image. Disappeared, beginning at top. Lower left corner went next.

Lower right corner was slow to go. Reappeared, beginning with lower left corner. Disappeared again almost immediately. Reappeared, beginning at bottom. Quickly disappeared. Reappeared faintly; then vanished.

Stimulus: Milton-Bradley yellow, 10 by 10 cm. After-image observed on field of closed lids. Time of stimulation, 30 sec. Distance of *O* 1 meter.

Gentle general streaming dimmed after-image. Lower right-hand corner cut off by streams, moving on short curves. Cleared. Stream from below moving from right to left swept out lower right corner and bottom. Cleared. Stream swept from right upper corner diagonally to lower left; immediately turning back and describing a sinuous path, swept out all but upper left and lower right-hand corners. They, too, were soon involved. Cleared, beginning at lower right and upper left corners. Two streams coming from below, left and right, joined and passed upwards across after-image, sweeping it out. They turned and apparently wound back and forth over after-image several times, causing a long disappearance. Lower left corner cleared first. Light stream swept across from left to right and almost blotted out image. It turned broadly upwards, then sharply downwards as a heavy stream, blotting out image completely. Cleared, beginning at upper left corner. General agitation over after-image (convection-current effect). Colors of background and after-image mingled in the general swirling. After-image disappeared. Cleared. Stream started at bottom, bent towards right, turned on itself towards left, again upwards and towards right, and then downwards in broad S-shaped curve. After-image was blotted out. Faintly reappeared. Almost immediately was involved in a general swirling and vanished.

The next two observations serve, further, to demonstrate that when a stream sweeps across an after-image area, causing the after-image to disappear, it carries with it the visual quality, color and brightness, of the area from which it proceeds.

Stimulus: a strip of Milton Bradley standard yellow paper, 42 by 4 cm. on a sheet of Milton-Bradley standard blue paper, 52 by 59 cm.; giving as after-image on the field of the closed lids, a reddish blue strip on a reddish yellow background. Time of stimulation 30 sec. Distance of *O* 1 meter.

First the yellow background could be seen streaming gently over the after-image, gradually dimming it. Swirl of complicated curves blotted out whole after-image. Cleared slowly, and after-image could be seen here and there at the less dense places. Gradually cleared all over. Circular swirl cut out centre and about two-thirds of upper half. Cleared. Another swirl cut out small area at centre and moved diagonally upwards and towards right. Centre cleared. Streams, sweeping from right to left, joined at bottom of after-image, and traversed its entire length, returning upon themselves on curves having the shape of an ellipse. After-image cleared beginning at bottom. Lower part of after-image cut off by stream sweeping across to right, which turned and went obliquely towards left and upwards, cutting out centre. Cleared at bottom first. General swirling. At some places after-image was carried out into background, and background carried in; so that after-image presented irregular outline. Soon swirling became more violent and after-image and background intermingled. After-image became indistinguishable. Did not reappear. (In every disappearance the stream could be seen to carry the yellow of the background over the strip. This was especially

noticeable when the disappearance was progressive, from part to part. When, *e. g.*, a swirl, expanding, involved successively more and more of the image, the front of swirling yellow could be seen to encroach upon the blue at each revolution.)

Stimulus: a strip of Milton-Bradley standard yellow paper, 42 by 4 cm. on a sheet of Milton-Bradley standard blue paper, 52 by 59 cm.; giving as after-image on a sheet of engine-gray cardboard a strip of blue on a background of yellow. Time of stimulation 30 sec. Distance of *O* 1 meter.

Dimmed all over. Went out at centre, then at top and bottom. Reappeared. Bottom swept out; then whole image. Reappeared. Section in middle of upper half went out, followed almost immediately by section in middle of lower half. Both reappeared. Whole after-image blotted out. Reappeared, first at bottom. Top and bottom went out, followed by centre. Centre reappeared first. Long, slender, crescent-shaped section disappeared from right hand upper, then from left hand lower portion. Reappeared faintly, beginning with right hand upper corner; then whole image disappeared. Reappeared. Lower part disappeared. Reappeared momentarily; then whole image vanished. Reappeared faintly, and vanished. (At each disappearance, the after-image area occupied by the blue strip took on the yellow of the surrounding background, instead of preserving the gray of the cardboard. In many cases it could be seen to do this progressively; *i. e.*, the yellow would begin at a corner, an edge, etc., and spread in the direction in which the disappearance of the strip was taking place. The phenomenon was very clear, *e. g.*, when a corner, bottom, or what not went out, and the disappearance spread, finally involving the whole image. This type of disappearance, when observed on the closed lids, generally showed a swirling stream which spread centrifugally until the whole after-image area was swept over.)

4. The effect of streaming on the flight of colors is threefold. First, a gentle streaming may merely dim the color. Secondly, more intensive streaming advances the color changes one or more stages. When the change is advanced only one stage, the image sometimes does, and sometimes does not return to the preceding stage, when the stream has passed over. When the change is advanced two or more stages, the image apparently always returns to the initial stage, or to the initial stage but one, when the stream has cleared away. Thirdly, when the streams are strong and heavy, the image is blotted out completely, returning to the initial stage when the stream has passed on either abruptly, or quickly through the series of color changes,—most frequently in their inverse order, but sometimes in irregular order. These effects cannot be due to a shadow cast by the stream upon the retina; for shadows, like any reduction of the illumination of the retina, push the color change in the inverse direction. Hence we have here additional evidence that the locus of the physiological condition of streaming is not anterior to the retina.

The following is a description of the effect of streaming on the flight of colors.[1] An account of the phenomenon as it

[1] All the phenomena described in connection with streaming are

appears under still better conditions has been given above (after-image from the sun's disc).

The stimulus was afforded by a triangular opening, 1 by 2 ft., in a curtain near the ceiling of a closely curtained room. *O* was seated about 10 ft. from this opening, and looked up through it directly at the brightly illuminated sky. The sash of the window was lowered. In line with the centre of the opening was a patch of bright, fleecy clouds. Thus the stimulus consisted of a brilliant blue triangle with a bright white patch at its centre. When stared at for a long time, *e. g.*, for 5 min., the triangle underwent the following qualitative changes. The white patch at its centre became gradually dimmer. Finally, it became completely overcast with the surrounding blue. This was concomitant with intensive streaming of the swirling type. It cleared somewhat; then the whole triangle changed to a deep, saturated pink. After remaining in this stage for a short time, it changed again to blue, and finally once more to pink. Here the observation ceased. When the after-image was to be traced, *O* fixated the centre of the opening for about 20 sec., and then covered the closed eyes with a black cloth. The observation was thus made in a well-darkened field of vision. The report is as follows.

After-image developed as light faintly reddish blue. Fluctuated several times between this and yellowish green. (Thus far, as it happened, the streaming was not intensive.) Finally settled into yellowish green. Heavy streams frequently swept across, carrying it completely out. On reappearing, it came directly back to yellowish green once. The remaining times it reappeared first as deep red, then quickly changed into yellowish green. The yellowish green area grew smaller as fluctuation went on, leaving a growing border of deep red. Next fluctuation began from yellowish green to deep red, as a result of less intensive streaming. The yellowish green area was swept off, as if it were an upper layer, leaving the purplish red underneath and further back. One could see the yellowish green streaming raggedly beyond the after-image. This was very plain at times. Once a narrow stream was observed to cut a channel through the yellowish green near the toe of triangle, exposing the deep red apparently beneath. Disappearances also took place at this stage as result of heavy streaming. After-image finally settled down into deep red. This layer seemed to be noticeably farther back in the field of vision than the other color layers. Disappearances were quite frequent, and were plainly the result of streaming. This stage lasted relatively a long time. Next faint stages respectively of dark blue and dull dark yellow were noticeable. Fluctuations were frequent and disappearances long. There was the usual connection between fluctuation and streaming.

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noticeably plainer when the observation is made in the higher altitudes. Whether this result is due solely to the condition of illumination there found, which facilitates observation (especially when made in daylight on the field of the closed lids), and conceivably induces a more or less special retinal state, or whether indirect physiological influences are at work, the writer has no means of deciding.

The following is a variation of the streaming phenomenon, not observed in connection with after-images. It is given as possibly throwing some light on the physiological condition of streaming from a slightly different angle. The observation was made out of doors in Colorado, early in October, near the middle of a cloudless day. The light stimulation was very intensive.

Sometimes when the eyes, having been exposed to the bright diffuse light, were closed, and the field of vision had settled, one saw scattered over it here and there, and fairly close together, islands or patches slightly darker than the background, presenting a porous appearance, due to a peculiar mottling of lighter and darker gray. These patches were not after-images. They were, however, readily seen to be carried along and broken up by the streams, the parts taking the velocity of the stream current. Streams could be seen to cut channels through groups of the patches. The patches themselves seem to be conditioned by some mobile material, which shares in the general streaming.

Another phenomenon, which seems to indicate that there is even a mass mobility of the material which conditions visual sensation, is described as follows. The observation was made under the same conditions as the last.

When one has two or more after-images of the sun's disc close together, they will often be seen soon to merge into one. Sometimes a channel cuts across from the one to the other, and the two gradually draw together into a more or less circular form. Again, the one will be seen to move bodily towards the other, finally uniting with it.

5. That there is a dependence of streaming upon eye-movement cannot be doubted. This dependence is shown in two ways. First, when an eye-movement is noticeable, or is made voluntarily, a heavier stream is started in the apparent tangle of swirling in the direction of the eye-movement. Secondly, whenever involuntary eye-movement is increased, as by previous long fixation, by a faulty centering of the after-image upon the retina, etc., greater commotion is noticeable over the streaming area. That there is a movement of this material, independent of the effect of eye-movement, is also probable; but the heavy streams that intermittently blot out the after-image are doubtless determined by eye-movement.[1]

[1]What the nature of the streaming material is we shall not attempt to decide, further than to point out that the results show it to be visually active. Metabolism requires that there be a diffusion of lymph over the retina. We might, then, identify the streaming material with this metabolic substance, making it the vehicle of both catabolic and anabolic processes. The anabolic material is conceivably in part disintegrated visual substance which retains for a time its power to condition visual sensation, as is shown by the streams bearing with them the visual quality of the region from which they come. Thus by weakening the after-image through hastening metabolic change, and by setting up strongly the sensation of the region from which the

c. When once we have established the connection between fluctuation and eye-movement on the one hand, and eye-movement and streaming on the other, explanation goes comparatively smoothly. The results obtained by varying the steadiness of fixation and by increasing the time of stimulation present no especial problem. There is in these cases merely an increase or decrease of eye-movement, and a corresponding increase or decrease in the streaming activity, with a resultant increase or decrease in fluctuation. With the remaining methods, however, the situation is different. They will be considered in turn.

(1) We have found that fluctuation occurs only within a limited region of after-image areas. Probably the most difficult problem that fluctuation sets to theory is this effect of variation of area. Before it, the oscillatory theory seems to break down absolutely.

Considered with regard to area, after-images naturally fall into four classes: small images which fluctuate little or not at all (for our observers, images with an area of 1.5 by 1.5 cm. and less); larger images which fluctuate over their whole area; still larger images which fluctuate in parts; and quite large images which do not fluctuate at all. Now this grouping is just what we might expect from the nature of the streaming phenomenon. It derives directly from the following facts: that streaming does not cause disappearance unless the stream comes from a part of the retina undergoing different stimulation; that the streams have a more or less definite form, *i. e.*, that they sweep across this or that part of the after-image, preserving pretty clearly defined borders; that vigorous streaming apparently occurs only over a somewhat limited region about the point of regard; and that the centre of the field of vision is always in a state of more or less violent swirling. Here the streams are narrow and swift-moving;[1] as we pass towards

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streams come, heavy streaming may temporarily obscure the after-image. It is, however, useless to work out in detail what, with our present knowledge of visual processes, can at best be but a mere conjecture. We desire to lay stress upon nothing except the observed facts.

[1] The direction of streaming is, as we have seen, determined or modified by eye-movement. The lines of direction described by all the points on the moving retina, for the various directions in which the eye moves, crowd together in its central portion; hence all the streams, since their directions are determined by the moving retina, converge towards its centre. This accounts for the narrowing of the streams, and the consequent more rapid motion of the streaming material. More or less continuous commotion at the centre must also result from these conditions; and the twisted, swirling, tangled patterns are produced by the many-times compounded motions. The centre of the retina is thus least liable to adaptation and after-image

the periphery, the swirling becomes more diffuse, and the streams are broader, and more widely separated both in space and time.

For convenience of discussion, therefore, the retinal field may be divided into four zones, each one of which usually, but not always, contains different stages of the same stream. The streams form near the periphery of the retina, and tend to move towards its centre. In the first or central zone, streaming is practically continuous. Here the streams are narrow, swift, and often crowded together. The second zone is made up in part of cross-sections of the streams found in the first, and in part of streams whose directions have been changed before they reached the first zone. Here the streams are broader and less swift and vigorous. The streaming at any given point is discontinuous; a given segment of the zone is streamed over at irregular intervals. In the third zone are found, in general, the source and the upper courses of the streams passing across the first and second zones. The streaming here is still more discontinuous, and the streams are still broader and more sluggish. The fourth zone lies beyond the area of observable streaming.

The infrequency or entire absence of fluctuation of the small images of the first group is explained by the fact that they lie wholly within the first zone, the region of most active commotion. Hence, when they have once reached the dimness at which disappearance begins, there is not sufficient lull in the streaming for reappearance to occur. The records show less eye-movement for the images of the first than for those of the second group. Here we come upon an exception to the general law of the effect of eye-movement upon fluctuation; for this reduction of eye-movement favors rather than decreases the fluctuation of these small images. It is, however, readily intelligible that a more continuous eye-movement, by causing more continuous streaming, would give even less opportunity for reappearance.

The images of the second group extend beyond the limits of the central zone; and the continuous streaming of this region does not cause them to disappear, since to do so the streams must come from a region of different stimulation. They lie, however, within the second zone, where the streaming is still vigorous though not continuous. A broad heavy stream sweeps in from the outside, and may either blot out the whole image at once (this depends upon the relative sizes of stream

effects. This conclusion tallies with well-known facts of vision. The centre of the retina is the region of clearest vision; adaptation there takes place less quickly, and the correlated after-images develop more slowly.

and image), or may at first efface only a part. Then, as the stream compounds with other streams, the whole image will become involved. When the commotion subsides, the image reappears, remaining until blotted out by another stream or stream-system. Since we are now in a region of only occasional streaming, increase of eye-movement must increase the frequency of fluctuation, by increasing the number of streams that sweep across the image. There is, however, sufficient intermission in the streaming for reappearance to take place. Continuous voluntary eye-movement would probably produce continuous streaming over this region; but, under the conditions of ordinary fixation, we have a fluctuation which is proportional to the frequency and range of eye-movement.

The images of the third group are still included in the region of streaming. They lie within the borders of the third zone, but are too large to have their whole area involved at one time by a single stream or stream-system. So we have the phenomenon of fluctuation in parts. As in the previous case, increase of eye-movement increases streaming, and accordingly increases frequency of fluctuation.

The images of the fourth group cover the whole area of effective streaming. Their borders lie in the fourth zone; and consequently fluctuation does not occur. The streams that twist about over the surfaces of these images do not come from a region of different stimulation, consequently do not blot them out.[1]

(2) We found that the form of the stimulus affects the frequency of fluctuation and the duration of the after-image. The stimuli used were strips and squares of equivalent areas. We now have to explain, first, the shape of the curve of frequency for the strip-images. An increased length of strip, while it produces practically the same effect on eye-movement as increased area of square, does not give the same shape to the curve. With the squares the curve, after reaching its maximal height, bends down rather sharply to the abscissæ;

[1] The explanation in this and the following sections may seem somewhat complicated; but the facts are themselves complicated. The results of observation are recorded as they were obtained, in no wise modified to suit the needs of theory. The phenomena of streaming and the phenomena of fluctuation were investigated independently and at different times. The details of streaming, its patterns, zones, etc., were worked out, and in part verified, a full year before the results on fluctuation given in the foregoing tables were obtained. After those results had been obtained, however, for variations in size, form, arrangement, etc., of stimulus, the present investigations were begun, with projection of the images on the field of the closed lids, in order to determine the relation of the various types of fluctuation to the various types of streaming. Thus our theory is, in reality, a description of what actually takes place in observation.

with the strips, it dips down very little. The explanation is that the squares, as they grow larger, come to include the whole of the noticeable streaming area, while the strips do not. The strips can, accordingly, always be swept across by streams coming from a region of different stimulation. They can be blotted out, while the squares cannot. The shape of the curve for the strips is very like that for the squares until the maximal height is reached; up to this point streaming affects both strips and squares alike.

We have to explain, secondly, the fluctuation of strips and the partial absence of fluctuation of squares of equivalent area. The explanation lies in the difference of the retinal zones. The squares fall within the first and the innermost part of the second zone. The strips, in proportion as they are included within the first, second and third zones, show the phenomena of fluctuation characteristic of these regions.

(3) We found that the arrangement of the stimulus, with reference to the direction of greatest eye-movement, affects the frequency of fluctuation and the duration of the after-image. Narrow strips of varying length undergo more frequent fluctuations and have a shorter duration when the direction of greatest range and frequency of eye-movement is across the strip, than when the inverse arrangement obtains. The reason is clear: the streams must be more effective to produce disappearance when they sweep across the narrow after-image, than when they traverse its length. Suppose, *e. g.*, that a narrow strip is placed with its length first in the vertical and then in the horizontal plane. Let the eye-movement, in both cases, take place in the horizontal plane. The vertical strip can be more effectively swept by streams coming from a region of different stimulation than can the horizontal strip. Accordingly we find greater frequency of fluctuation and a shorter duration of the image in the former case than in the latter. Conversely, when the movement is in the vertical plane, and the strip is arranged first vertically and then horizontally, the opposite effect should be produced. The tables show that this is the case.

In the experiments on natural fluctuations, the greater range and frequency of eye-movement, for all observers, were in the horizontal plane. Hence greater frequency of fluctuation and shorter duration should have been observed when the strip was arranged with its length in the vertical plane. The tables show that this expectation was realized.[1]

[1] The character of the disappearance is somewhat different, according as it is due to voluntary eye-movement or to natural fluctuation. In the former event it is more abrupt, and more nearly covers the whole length of the image. In natural fluctuation, the image usually

(4) Having thus ascertained the part played by streaming in the determination of the duration and fluctuation of the after-image, we can understand how it is that results obtained when the fluctuations were produced by involuntary eye-movement, varying in amount from method to method, could be duplicated by results obtained when the fluctuations were produced by voluntary eye-movement, constant from method to method. There are two possible reasons. First, there was present in both cases a variable amount of involuntary eye-movement; and secondly there was in both cases the same distribution of the zones of streaming.

There can be no doubt that voluntary eye-movement, while it lessened, did not entirely prevent involuntary movement. In the variation of this latter, from method to method, we might find a basis for the variation in results obtained, and therefore an explanation of the duplication. On the other hand, there is strong evidence that the concomitant involuntary eye-movement was not the direct cause of fluctuation. The disappearances always followed directly upon the voluntary movements, which must, therefore, be regarded as the immediate cause of fluctuation. The involuntary movements could have functioned only indirectly, by way of weakening the after-image, under certain experimental conditions, and thus rendering it more liable to obliteration by the voluntary movements. Obviously, then, the distribution of the zones of streaming is the more important factor.

It is not difficult to see how these two factors co-operated to produce our results. If there were no variation of involuntary eye-movement, from method to method, strict duplication should result when the fluctuations are produced by voluntary eye-movement. If it were not for the identical distribution of the zones of streaming, duplication could not result at all. A consideration of the two factors together enables us to explain the results obtained.

(5) The peculiarities of fluctuation in indirect vision are readily explained as a result of the distribution of the zones of

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goes out in successive parts, quickly, until it has disappeared. The difference reflects the nature of the eye-movement. The voluntary movement is a single sweep, out and back, of considerable strength and range. A broad current of the streaming material is thus carried across the image in the direction of the eye-movement, and blots it out at once. The involuntary movements occurring in the case of natural fluctuation are irregular in direction, range and frequency, and usually come in groups. They therefore start a number of streams in different directions, and usually in quick succession. One stream is often seen to sweep across this part, another across that; until finally the whole image becomes involved before any part has had time to clear.

streaming. When a small after-image is observed, first in the central part of the field, and then successively farther and farther out from the centre, there is first an increase in fluctuation, then a decrease, and finally an entire cessation. Now we have seen that an image in the central zone of streaming, once it has disappeared, is kept from reappearing by the continuous commotion there present. As it passes from the central zone outward, into the region of occasional streaming, fluctuation must increase up to a certain point (probably the limits of the second zone), and thereafter decrease, ceasing entirely when the image passes beyond the range of noticeable streaming.

(6) Fechner,[1] Helmholtz,[2] and others maintain that blinking and movement of the head, as well as movement of the eyes, cause the after-image to disappear. Both of these movements, however, result in eye-movement, and hence may be supposed to be only indirectly causes of disappearance.

With regard to blinking, O. Weiss says:[3] "Beim Lidschluss zeigt sich eine Bewegung des Bulbus erst nach oben innen, dann nach oben aussen." This is called Bell's phenomenon.[4] The movement can easily be felt when one presses the finger with moderate firmness on the lids, above and to the temporal side of each bulb, and blinks vigorously. Von Michel[5] thinks that this movement-complex is controlled by the cortex, while Nagel[6] believes it to be a reflex, due to the pressure of the edges of the lids upon the cornea. However this may be, there is distinct eye-movement, in at least two directions, with every closing and opening of the lids; that is to say, there is ample ground for considering eye-movement to be the more immediate cause of the disappearance of the after-image.

Again, even if the eye were stationary in its socket, movement of the head would affect the streaming phenomenon very much as movement of the eyes does. The streaming material would traverse the retina in the opposite direction to that of the movement.[7] But the eye is not thus stationary; movement of the head results either in a movement of the eye in the opposite direction, or in this together with a readjustment of the eye in accordance with the changed position of the head. And there is, further, a rotation of the eye about its horizontal axis, which, according to Donders, opposes the rotation of the head

[1] Ann. d. Phys. u. Chem., L, 1840, 221.
[2] Phys. Optik, 510.
[3] Nagel's Handbuch d. Physiol. des Menschen, III, 1905, 471.
[4] Philos. Transact. of the Royal Soc., 1823, 166, 289.
[5] Beitr. z. Physiol., Festschr. f. Fick, 1899, 159.
[6] Archiv f. Augenheilk., XLIII, 199.
[7] This would be in the same direction as the movement of the field of vision, the converse of what happens with eye-movement. The effect on the after-image, however, would be essentially the same.

and is of equal amount in both eyes. In the case of a sudden inclination of the head, Mulder[1] found a momentary torsion of 20°. His conclusions as regards permanent torsion bear out those of Skrebitzky.[2] Nagel[3] found that movements of torsion occur if the head or the head and body together are passively moved.

In fine, then, the effect upon the after-image of blinking and of movements of the head presents no especial problem to theory; in both cases definite and measureable eye-movements take place. Eye-movement, as determining or modifying the streaming phenomenon, explains fluctuation under these conditions as readily as it explains the fluctuations which occur under the conditions of normal fixation.

III. Conclusions and Restatement of Thesis.

The conclusions to be drawn from the foregoing experiments, with regard to the fluctuation and duration of the negative after-image, are as follows. (1) The fluctuation of the negative after-image represents a real intermission of sensation. It is not an artifact, due to observation under the conditions of light adaptation, for it occurs as readily in a darkened as in a light field of vision. (2) Fluctuation is not grounded in the nature of the after-image process. It is caused chiefly by involuntary eye-movement. (3) Eye-movement causes the fluctuation and decreases the duration of the negative after-image by conditioning or modifying the streaming over the retina of some material capable of affecting the visual processes.

Enlarged and restated in the light of these conclusions our thesis is this. (1) The intermittence of minimal visual sensation is a phenomenon of adaptation. (2) Adaptation is rendered intermittent chiefly through the influence of eye-movement. (3) Eye-movement interferes with adaptation in three ways. (*a*) It decreases the total time of stimulation. The more eye-movement there is, the less intensive will be the impression made upon the retina. (*b*) It affords time for the after-image to die away, or (in terms of adaptation) it gives opportunity for restoration, proportional to the length of time during which the stimulated area is relieved. And (*c*) more immediately, it determines or influences the washing or streaming over the retina of some material capable of directly affecting the visual processes. Further evidence for this thesis will be adduced in later papers.

[1] Archiv f. Opthalmol., XXI, 1, 1875, 68.
[2] Archiv f. Opthalmol., XVII, 1, 1871, 107.
[3] Archiv f. Opthalmol., XVII, 1, 1871, 237.

MINOR STUDIES FROM THE PSYCHOLOGICAL LABORATORY OF CLARK UNIVERSITY

COMMUNICATED BY EDMUND C. SANFORD

XXI. A PRELIMINARY REPORT OF EXPERIMENTS ON TIME RELATIONS IN BINOCULAR VISION[1]

By TIMOTHY J. STEVENSON and E. C. SANFORD

The stereoscope, as ordinarily arranged, presents at the same time to each eye an appropriate picture. In a special form, devised by Prof. Münsterberg, however, the pictures are not presented simultaneously, but each eye sees its own picture for an instant while the other eye's picture is covered.[2] Still earlier, Dvorák showed that stereoscopic vision was possible under circumstances similar to these, and described certain illusions depending on that fact,[3] Dvorák, and later Exner, studied also the least time interval that could be observed between visual stimuli offered separately to the two eyes.[4] The study now to be described belongs to this general group, but the particular questions with which it deals are slightly different from any of these. The first problem undertaken was that of determining what time interval, if any, may be inserted between the presentation of each picture to its proper eye without marked interference with the perception of stereoscopic relief; and the preliminary results to be stated have to do chiefly with what is to be observed when the interval is made so long that stereoscopic vision becomes difficult or impossible.

The Apparatus. The apparatus used was in general terms, a Wheatstone stereoscope, fitted with notched disks in such a way that one eye's picture was first exhibited automatically

[1] In view of the fact that Mr. Stevenson is no longer working in the laboratory and that the problem is about to be taken up by other hands, it has seemed best to make this report of results which seem to be demonstrated.

[2] Münsterberg: *Psy. Rev.*, I, 1894, 56-60, Studies from the Harvard Psychological Laboratory—a Stereoscope without Mirrors or Prisms.

[3] Mach: Analyse der Empfindungen, 1903, p. 196. Dvorák: Ueber Analoga der persönlichen Differenz, Sitz.-ber. k. böhm. Ges. d. Wiss. (math.-nat. Classe, März 8, 1872).

[4] Exner: Experimentelle Untersuchung der einfachsten psychischen Processe. Pflüger's Archiv, XI, 1875, 402 f.

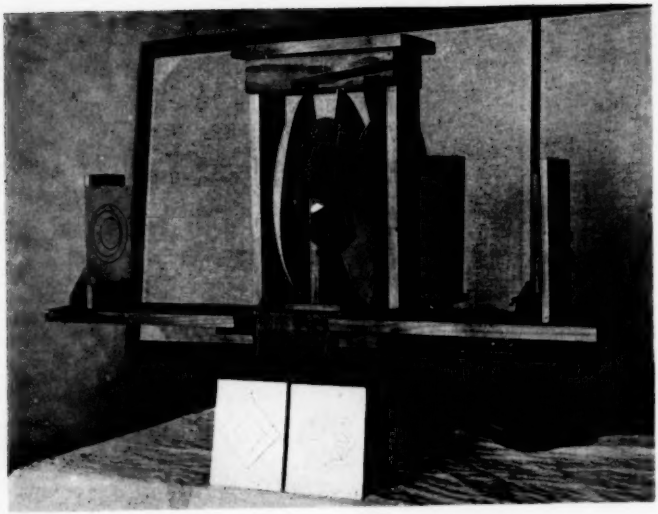

PLATE I

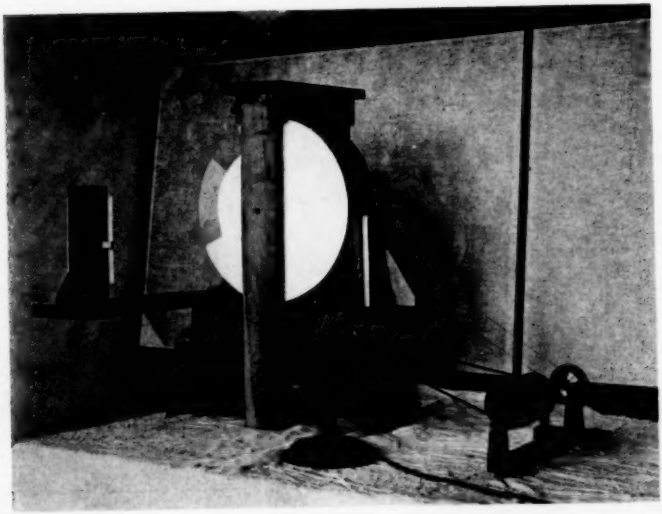

PLATE II

for a brief time, and then, after a known time interval, the other eye's picture was similarly exhibited for a time equal to the exhibition of the first eye's picture. The details of the arrangement will be made sufficiently clear by the accompanying plates and plans.

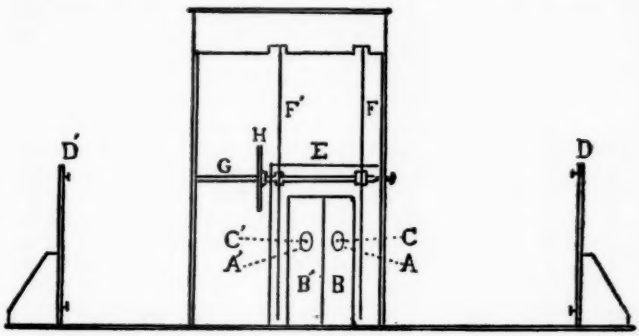

FIG. I

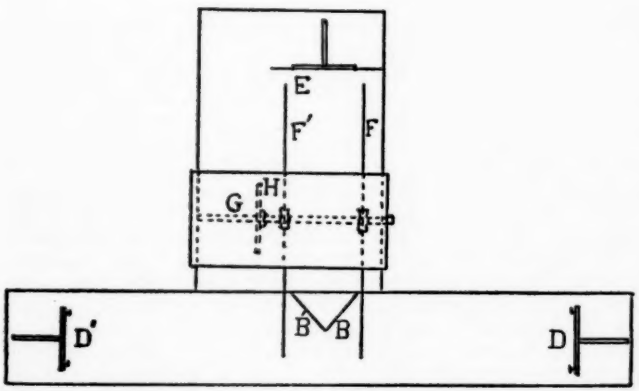

FIG. II

Plate I shows the apparatus as viewed from in front; Plate II, the same viewed from the side. Fig. I is a front elevation of the apparatus, and Fig. II its ground plan. *A'* and *A* in Fig. I are two plane mirrors, each about an inch and one-half in diameter, fastened over corresponding holes in two upright

panels, B' and B, standing at right angles to each other (Figs. I and II). In order to secure easy and perfect fixation, the silvering of each mirror was removed from a little spot at the centre, through which the observer looked at a white fixation point on the black background, E, which was itself carefully set so as to lie in a definite plane of the stereoscopic solid. Into coincidence with the fixation point just mentioned were also brought certain symmetrical points of the reflected images of the diagrams, carried by the panels, D' and D—usually the centre points of the larger circle or polygon.

The rotating disks used to secure the separate presentations of the diagrams are indicated by F' and F (Figs. I and II). These disks were 16 inches in diameter, and stood 4.5 inches apart. In the edge of each was cut a square notch, 30° wide and 2.5 inches deep. The disks were carried by a horizontal axis, G, lying parallel to a line joining the centres of rotation of the eyes of the observer, and 6.5 inches behind the centre of the mirrors. On this axis they were held by nuts which allowed them to be moved stiffly with reference to each other, and made it possible to set the notches in them quickly at any angular distance from each other up to 150° (180° minus 30°). The precision of the setting of the disks was tested by means of a straight edge attached to the frame of the apparatus, and a scale of degrees marked off on one of the disks.

The disks were rotated by an ordinary fan-motor, actuated by the commercial alternating current of the city, working through a series of pulleys to reduce the speed. The final pulley upon the axis of the disks is shown at H in the figures. This pulley was connected with the rest of the driving apparatus by a loose belt, running over an idle pulley serving also as a belt tightener. By this means the disks could be stopped or started as often as necessary without interrupting the movement of the rest of the driving apparatus. The rate of such a motor is usually quite constant, and in this case was tested before and after each experimental sitting (except one) by three timings of one hundred revolutions of the disks, each taken with a stop watch reading to one-fifth of a second.[1] The average rate found was slightly over 80 seconds per hundred turns. The greatest variation found in any single group of three countings was 0.4 seconds, and the extreme variation between timings taken in different days was 3.2 seconds. More exactly, the average time for one rotation of the disk was 0.804 seconds,

[1] On one or two occasions during the experiments, the motor clearly slowed up for a few seconds at a time, because of a temporary interruption of the current, or for some similar cause. At such times observations were, of course, suspended until the normal speed was resumed.

and thus for one degree 2.23σ; for 10°, 22.3σ; for 20°, 45σ; for 30°, 67σ; for 60°, 134σ; for 90°, 201σ, and for 150°, 335σ.

In most of the experiments here to be considered, the right hand picture of the pair was shown first, except of course for the setting at 150°, when the pictures simply alternated at intervals of 335σ measured from the end of the period of visibility of one to the beginning of that of the next. The exposure time for each picture was constant at 67σ seconds (30°) or in common fractions, about 1-15 of a second.

One each of the three pairs of stereoscopic diagrams used is to be seen in Plate I. The one in the holder at the left and the right hand one of those in front of the instrument (designated in the notes as Diagrams 13 and 15) are familiar forms. The inner and middle circle of Diagram 13, however, were colored; the inner one red, the next violet, while the outermost was black. This difference in color was unnecessary and a disadvantage, as it possibly tended to suggest monocular relief in ways which would not have been present with figures all in black. Diagram 15 was drawn entirely in black, but was unsatisfactory for another reason; its oblique lines introduced definite tendencies to monocular relief, according as one or another of them was fixated, and these monocular tendencies sometimes co-operated with and sometimes opposed the binocular relief. The other figure (known in the notes as Diagram 14 and shown in Figure III) is a less common one, copied from

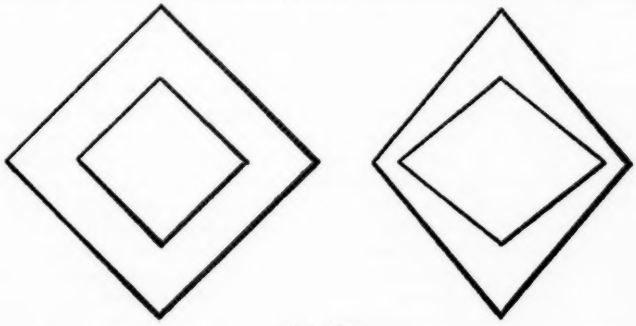

FIG. III

a collection of figures belonging to the Clark Laboratory. To those unfamiliar with it, this figure does not usually suggest, when uncombined, the form brought out by combination. When examined stereoscopically the diagrams show two diamond shaped planes intersecting at an angle of nearly 90°.

Reversal of any of these diagrams in the holders, of course,

brings about reversal in the apparent relief. It was easy, therefore, with a little care to begin a test without the observer's knowing what kind of relief he was to expect, and this was the usual procedure.

Of the large disks three sorts were used; one of black cardboard, one of white (the back of the black disks in this case, which gave a fair, but not exceptionally intense white), and one of a medium gray. These differences in brightness are by no means unimportant, for the disks not only shut off the vision of the pictures after the required interval of exposure, but the light which they reflect furnishes a general stimulation of the retina which has a profound effect upon the duration of the after-images of the diagrams. The illumination was ordinary day-light and, on several of the days, when it was necessary to experiment, varied considerably.

Method. The experimental procedure in the case of the more systematic experiments was as follows: A pair of the diagrams was adjusted in the holders and covered up to prevent the observer from knowing what form of relief to expect. The disks were then set with their notches at a considerable angular distance (usually 60°, though sometimes 90° or 150° was chosen), and put in motion. The observer took his place at the instrument, looked at the background and reported what he was able to observe. The experimenter, meanwhile, recorded the observations, asking questions when necessary to make the record definite. The observer was allowed to adjust his head and to use his eyes in the way most convenient to him. Occasional differences, due to fixation and movement, were reported. After observations with a large interval, the smaller were used in regular sequence: 30°, 20°, 10°, 0°, and —30°. The numbering of the scale of degrees was arranged to show the interval between the ending of the exhibition of the first picture and the beginning of that of the second. Zero degrees, therefore, means that one exhibition began the instant the other ended, and —30° means that the exhibition of both began at the same instant—that they were strictly simultaneous.

When observations had been made upon one pair of diagrams at the standard intervals, another pair was substituted and the process repeated. Similarly, when all the diagrams had been worked through with one pair of disks, another pair of disks was placed upon the axis, and the observation of all the diagrams at all intervals was again undertaken. The matters to which observation was especially directed were the nature of the stereoscopic relief, the apparent movement of the figures, and the character of the after-images.

Of the two chief observers, one (S) has had quite a little experience with work of this kind. The other (T) has had

only a small amount of general training in the psychological laboratory. A third observer (P) was, like the first, experienced in psychological experimentation. The note books contain one full set of observations for S and T with all the disks and all the diagrams, besides the records of some incidental testing taken while the apparatus was being perfected and at odd times during the taking of the regular set. For P, the records were taken with all the diagrams, but part with the gray and part with the white disks.

Results. The small number of systematic experiments and the complexity of the phenomena involved preclude our making any quantitative answer to our first problem, except a negative one. It is qualitative statements chiefly that we can make, and these for the most part with reference to what happens when the interval between the exhibitions of the two pictures is so long as to make stereoscopic vision difficult or impossible.

Our experiments have led us, however, to the conviction that *practically no interval whatever can be inserted between the periods of excitation of the two retinas* (including the duration of the after-image as a part of the first excitation) without destruction of the stereoscopic relief. It seems likely, on the contrary, that stereoscopic vision depends strictly upon the simultaneous excitation of the two halves of the visual apparatus.[1] Further systematic experimentation on this point may show that a very minute interval can be inserted, but it will certainly prove small even in comparison with the duration of the positive after-image.

Upon the following points, however, our observations have been so uniform and consistent that we feel justified in making a definite report with regard to them.

1. When the interval between the pictures is great enough to interfere with the usual stereoscopic apprehension of the diagrams, *their parts are apperceived as in motion.* They seem to change quickly from the position they occupy in one eye's diagram to that which they occupy in the other. This is especially true of the parts that fall upon non-corresponding retinal points, but it is also true to a certain extent of the parts that fall upon corresponding points, perhaps as a result of the relative way in which movement is usually perceived. Double images in the ordinary sense are not seen at such times and indeed cannot be seen until the periods of retinal excitation overlap and are thus, in part at least, simultaneous.

For Diagrams 13 and 15 this movement was chiefly a change

[1] In Prof. Münsterberg's instrument, the positive after-images probably outlasted the entire interval.

of place, a sudden sliding or leaping from side to side of the inner parts of the figure, the diagrams having been so adjusted as to bring the outer parts approximately upon corresponding points. This movement was not always strictly horizontal but at times in an oblique direction, though there was nothing in the position of the diagrams or the observer that would easily suggest a reason. In Diagram 14 the movement was an apparent change in the shape of the figure itself, diamond to square or *vice versa*. This movement of the parts of the diagram was most striking with the longer intervals, and gradually decreased as the intervals were taken shorter and shorter, until it finally disappeared when the setting reached 0° or —30°. In some cases, the movement was apperceived as an excentric rotation in the plane of the background instead of a leaping from side to side; and in a few cases, when the interval was short, the movement seemed to be to and from the observer in the third dimension, instead of simply from side to side. In most cases, however, the movement and the binocular relief seemed reciprocal phenomena, the one decreasing as the other increases. When the conditions are not present for the adequate perception of relief, the apperceptive process takes on automatically another form, the perception of movement. In rare cases they are partially combined.

2. *As the interval is shortened and the conditions become more favorable to the apprehension of stereoscopic relief, the relief seems not to come in suddenly in full amount, but gradually.* Let us say, for example, that, in Diagram 14 the relations are such that under the conditions of ordinary stereoscopy the right hand point of the inner diamond would appear two inches in front of the right hand point of the outer diamond. Then with the gradually decreasing intervals of our experiment it would appear at first, perhaps, only half an inch in front and would gradually draw forward as the time between the pictures lessened until with the 0° or —30° settings it would be seen at full two inches in front. A corresponding but opposite change in the amount of the relief was to be observed when the interval between presentations was gradually lengthened from simultaneity.[1]

The gradual alteration of the amount of stereoscopic relief

[1] It may be noted also in passing that it was usually the *advance* of some part of the figure from the plane of the fixation point *toward* the observer that was first and most easily to be observed. The location of the portions back of that plane seemed more difficult and was slower in coming to observation. A similar relation was demonstrated to one of us by Dr. J. Carleton Bell, in the Wellesley Laboratory, some weeks before our experiments began. We note in passing this confirmation of a result already obtained by him.

just mentioned, seems to us of some theoretic interest and so far as it goes to furnish an argument in favor of the theory that the perception of stereoscopic relief is due to a reflex tendency of the eyes to move so as to fixate the different portions of an object seen in relief (a tendency not by any means perceived as such, but simply in its result, the binocular relief), and especially to support Wundt's account of the nature of the complex local signs in binocular vision. If the matter were a reflex one, we might very well suppose that the degree of binocular central excitation, and accordingly of the tendency to movement, would be roughly proportional to the time during which a very brief stimulus was operative binocularly, and such a proportionality our experiments seem to indicate.

It may perhaps be suggested that this increase in stereoscopic relief with shortening time intervals was due, not to the particular reflex relations above mentioned, but to a general improvement of the conditions necessary for an apperception of a third dimensional kind. In other words that the relief seemed to grow greater as it actually grew clearer. We are not inclined to think that this is the real explanation, though of course the matter must await further explanation.

One other point has been emphasized in our own minds by these results and that is the rather misleading way in which binocular vision is often presented in the text-books. The subject is a complex one and much allowance is to be made, but still it is customary to talk of binocular vision as though it were due to an actual psycho-physical fusion of two simultaneously present but independent monocular images; whereas, it certainly should be regarded as the physiological result of a certain balance or distribution of excitations in a symmetrically constructed but unitary visual apparatus.

DISCUSSION.

The Method of Impression and Some Recent Criticism.

By E. B. Titchener.

In the course of a recent paper entitled *Die Grundformen der Gefühle*,[1] N. Alechsieff takes occasion to criticise the method of impression in general and my own work with that method in particular. I am not here concerned to offer a counter-criticism of Alechsieff's method and results; but I desire, so far as possible, to meet the objections which he urges against the method of impression.

I read with some surprise the following sentence: "In einer sehr eingehender Kritik hat M. Kelchner die Mängel der Eindrucksmethode hervorgehoben."[2] A second reading of Kelchner's article showed, however, that the statement has a certain justification. At the same time, it is distinctly misleading.

Kelchner[3] is recommending the use of the expressive method in connection with introspection. "Man hat," she says, "der Ausdrucksmethode gelegentlich vorgeworfen dass sie die Selbstbeobachtung vernachlässige." As a matter of fact it may be shown "dass die Selbstbeobachtung durch die Registrierung der Ausdrucksvorgänge in hohem Masse unterstützt werden kann." On the other hand, "ob *reine* Selbstbeobachtung imstande ist, den an sie gestellten Anforderungen zu genügen, muss bezweifelt werden." What Kelchner is criticising, so far, is *pure* introspection (italics K.'s), that is, introspection under casual, non-experimental conditions. The difficulties of pure introspection are two: unaccustomed direction of attention, and the fusion of affective processes with organic sensations.

It is clear that this pure introspection is not identical with the method of impression. Kelchner now proceeds to criticise, not the introspective value of that method, but the value of the introspections accompanying the method which she herself employed, the method of expression. There are three sources of error: liability to distraction of attention, with resulting scrappiness of observation; illusions due to the rules laid down for observation (*e. g.*, illusions of expectation); and inaccuracy of report. Kelchner seeks to show how and to what extent these errors may be combated in work done by the expressive method.

Alechsieff, however, goes on: "Sie findet dass diese Methode (the method of impression) alle Nachteile der reinen Beobachtung besitzt, und vor allem" the three just mentioned. That is to say, the three sources of error discovered by Kelchner "im Laufe unserer Untersuchung" by the expressive method are transferred bodily by Alechsieff to the charge of the method of impression, which Kelchner does not mention. I think that Alechsieff's statement may fairly be characterized as misleading.

There is, nevertheless, a certain justification for the statement.

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[1] Wundt's Psychologische Studien, iii, 1907, 156 ff.
[2] *Op. cit.*, 162.
[3] Archiv. f. d. gesammte Psychol., v, 1905, 107 ff.

Kelchner concludes her criticism by saying: "Unsere Erfahrungen . . . tun . . . die völlige Unzulänglichkeit einer Untersuchung dar, die lediglich die Angaben der Vp. verwendet;" and she refers in a footnote to Orth's "Gefühl und Bewusstseinslage." When we remember that Orth's thesis, the work of which was done with Külpe at Würzburg, was accepted in 1903 by Meumann as a Zurich doctorate dissertation; and that Kelchner's investigation, made under Meumann's direction and edited by him, was ready for the printer in Feb., 1904: it is a safe guess that Kelchner had Orth in mind throughout her criticism of introspection. In so far, therefore, as Orth employed the method of impression, Alechsieff's statement may be constructively justified.

The method used by Orth is the method of question and answer[1] which Wundt, in a somewhat different connection, has quite recently criticised.[2] I am inclined to think that Wundt's criticism goes too far.[3] And I suppose that, in a very general sense, the method of question and answer may be described as a method of impression. At the same time, what one ordinarily thinks of, when the method of impression is mentioned, is either the serial method or the method of paired comparisons:[4] so that Alechsieff's statement is, again, misleading. Now the method of impression, in this customary and narrower sense, is not open to Kelchner's objections. Since a long series of stimuli, or of stimulus pairs, is laid before the observer, there is every chance for a constant direction of attention. Since the introspection required is of the simplest kind, there need be no scrappiness of observation. Since the rules laid down for observation are of the same unequivocal sort, there can be no illusion of expectation, etc. Since the 'report' consists simply in writing down a number or a letter, or in pointing with the finger to the one of two impressions, the chances of inaccuracy are minimal. On the other hand, the method has definite advantages. It allows us to cover a very wide range of stimuli, within a given sense department, in a comparatively short time; it furnishes an easy way of testing the constancy of the affective judgment whether for different observers or for the same observer at different times; and as the affective experience is cumulative, all of the same order, it affords excellent opportunity, in the intervals between sectional series, for detailed introspective analysis. Moreover, it is the only method now in the field which holds out hope of a differentiation, a determination of the nature and number, of the affective qualities. And lastly, it combines objective and subjective control, as every experimental procedure must do, and effects this combination more simply and more reliably than does the method of expression. I return to this point later. In the meantime it is enough to point out, first, that the introspective difficulties which Kelchner finds are, admittedly and evidently, difficulties characteristic of the method of expression and of that alone; and secondly that a method which, as Kelchner and Alechsieff put it, "lediglich sich auf die Angaben der Beobachter stützt," cannot be identified outright with the method of impression.

I turn to Alechsieff's criticism of my paper in the Wundt *Festschrift*. The critic's first point is that I am to blame for not having taken part in the experiments, "obschon sie nur auf Grund der subjektiven Methode gemacht worden sind."[5] This objection seems to rest upon a sheer misunderstanding. I explain in the paper itself that the work

[1] The method really ranges from Brahn's Reizmethode (Philos. Studien, xviii, 1903, 133) to the Ausfragemethode proper; but there is no difference in principle.
[2] Psychol. Studien, iii, 1907, 301 ff.
[3] *Cf.* my remarks on Brahn, Philos. Studien, xx, 1902, 404.
[4] *Cf.* Wundt, Phys. Psych., ii, 1902, 267. The Reizmethode is not mentioned.
[5] *Op. cit.*, 167 f.

began with experiments of my own, in which I learned two things: that the required affective judgments might be passed without especial difficulty, and that introspection was facilitated by a particular phrasing of the instructions.[1] Alechsieff has apparently overlooked this paragraph. I then say that I took no further part in the experiments "als Versuchsperson," but that they were carried out "unter meiner directen Aufsicht." These statements mean simply what they say,—that I did not join the research groups, as observer, during the course of the published experiments: there is nothing in them to indicate that I discontinued my observations altogether. Indeed, I later promise for the future "eine exacte Verwerthung der Urtheilsdaten,"[2] which implies with sufficient clearness that I had gathered such data at first hand. Suppose that I had taken my place before the harmonical with the other observers: would not the critic have raised the cry of suggestion? Suppose that I had published my own curves: would not the critic have charged prepossession?

In his further criticism, Alechsieff confines himself to the objective aspect of my experiments, and says nothing of their subjective side. "Der Grundgedanke Titcheners ist der, dass es unmöglich sei, durch ein und denselben Reiz in derselben Weise zwei verschiedene Gefühlsqualitäten hervorzurufen. Dieser Gedankengang ist nicht zwingend."[3] But then it is not either my *Grundgedanke*. I quote from Hayes: "On the objective side there is the appeal to the 'curves.' . . . It would surely be a strange thing if a given set of stimuli affected a given observer by way of excitement-depression (or strain-relaxation) precisely as it affected him by way of pleasantness-unpleasantness. Coincidence might occur here and there; but the wider the range of observers, the larger the number of stimuli employed, and the more varied the type of the affective judgment, the less likely would it be, on the basis of the plural theory, that coincidence should appear. On the subjective side, again, there is the appeal to the introspection of the observers. If the observers declare that the affective judgment in terms of pleasantness-unpleasantness is direct, easy and natural, while judgment in terms of strain-relaxation and excitement-depression is forced, difficult, associatively mediated, etc., then the evidence of the method is in favor of the dual theory. And if, further, the observers state that their judgments of excitement-depression and strain-relaxation, so far as they are affective at all, are based upon pleasantness-unpleasantness, this evidence is proportionately strengthened. . . . The more numerous the observers, the more varied the stimuli, the more nearly exhaustive the affective categories, the more certain will the outcome be."[4] The method affords a twofold control, objective and subjective, and appeal to the subjective aspect is made with all plainness in my paper.[5] Alechsieff has overlooked these passages. He has also, publishing in August, 1907, overlooked altogether the work of Hayes, published in July, 1906.

I have no wish to deny that the method of impression is still in the first stages of its development. On the contrary, I believe that this characterization holds both of the serial method, in its two forms, and of the method of paired comparisons; still more of Brahn's stimulus

[1] Philos. Studien, xx, 1902, 388.
[2] *Op. cit.*, 390. Materials towards the analysis of the affective judgment have since been published from the Cornell Laboratory by Hayes (this *Journal*, xvii, 1906, 358 ff.); and further work, in continuation of Hayes' and my own, is now in progress.
[3] *Op. cit.*, 208; *cf.* 219. In the latter passage Alechsieff outlines a programme of further work, which I should have done well to undertake. This is always a safe line of criticism; but it would have come with better grace from a critic who had gone to the bottom of the work already done.
[4] *Op cit.*, 360 f.
[5] *Op cit.*, 389, 394, 394-6, 403, 405.

method, and its sub-forms of stimulus comparison and stimulus compensation. We must not forget, however, that the method of impression, in any form, has received less extended trial than has the rival method of expression. There is now a tendency to combine the latter method with an introspective procedure, and we shall know before long within what limits the combination is possible. At all events, it is to the impressive method, or to what may be termed the impressive aspect of the combined method, that we must look for an answer to the question of the nature and number of the affective qualities. I hope, therefore, that in meeting Alechsieff's criticisms I have done more than merely remove a few personal misunderstandings.

PSYCHOLOGICAL LITERATURE.

Measurements of Twins, by EDWARD L. THORNDIKE. Archives of Philosophy, Psychology and Scientific Methods, No. 1, Sept., 1905. New York, Science Press. pp. 64.

In this monograph Prof. Thorndike discusses by modern statistical methods the results of a number of mental and physical measurements made upon fifty pairs of twin children between nine and fifteen years of age. The mental tests turned upon the finding and marking of A's distributed among other capital letters; the finding and marking of words containing two designated letters (e. g. *e* and *r*) distributed among other words; the finding and marking of misspelled words in easy prose; adding; multiplying; and the writing of words opposed in meaning to words in a given list. The physical measurements included height sitting and standing, length, width and circumference of the head, length of certain finger joints and of the forearm from elbow to finger tip, besides notes as to resemblance in general appearance and in color of eyes and hair.

The results are discussed with reference to the degree of mutual resemblance of twins in comparison with that of other siblings (*i. e.*, children having the same father and mother), the degree of resemblance of the younger twins as compared with that of the older ones, the degree of resemblance in traits assumed to be little subject to training as compared with those in which training is assumed to be influential, and the degree of resemblance in mental traits as compared with the resemblance in physical traits.

The conclusions reached are: (1) that the mutual resemblance of twins in mental traits is about twice as great as that of other siblings (about .80 as against .40—unity being the standard of complete identity); (2) that the older twins show no closer resemblance than the younger; (3) that there is not much greater resemblance between twins in traits assumed to be much influenced by training than in others; and (4) that the resemblances in physical and mental traits are of about equal amount. In general "the form of distribution of twin resemblances seems to be that of a fact with a central tendency at about .80 and with great variability restricted towards the upper end by the physiological limit of complete identity."

In addition to these explicit results Prof. Thorndike draws from the figures and his interpretation of them certain inferences with reference to general questions of heredity, as, for example, that heredity is a much more important factor in determining the relative attainments of human beings than is environment; "that heredity is itself highly specialized, each minute feature of physical and mental make-up possessing its representative in the germs and varying more or less independently of other features of the same germ;" and that twins are probably derived from two ova, not from a single divided one.

The statistical method is a potent and delicate instrument and all English speaking psychologists remain in Prof. Thorndike's debt for his efforts, of which this paper is a part, to make modern statistical methods current in psychology; but it is still a machine, and as such incapable of changing the intrinsic character of the raw data submitted

to it and of interpreting the final figures which it produces. With reference to the mental tests Prof. Thorndike is himself careful to say that he does not regard the particular tests as an adequate measure of mental resemblances in general and that the conclusions reached have reference only to the traits tested. This should, of course, be borne in mind in estimating the justification and weight of the general inferences above mentioned. That Prof. Thorndike himself seems sometimes to forget this and to underestimate the intricacy of the action and reaction of heredity and environment is perhaps the chief criticism to be brought against the paper.

Full tabular statements of the original data in the case of the twins and of the various stages of the statistical evaluation are given; but so far as the reviewer has discovered, this is not the case for the siblings with whom the twins are compared. E. C. S.

Sociological Papers, III. By G. A. REID, W. MCDOUGALL, J. L. TAYLER, J. A. THOMSON, P. GEDDES, A. E. CRAWLEY, R. M. WENLEY, W. H. BEVERIDGE, G. de WESSELITSKY, MRS. S. WEBB, and H. G. WELLS. Macmillan & Co., Ltd., London, 1907. pp. xi, 382.

Like its predecessor (this *Journal*, xvii, 1906, 429), the new volume of the Sociological Society's publications contains eleven original papers, accompanied by discussion, written communications, and the author's reply. The high level of the two previous volumes is fully maintained. Indeed, it is probably safe to say that there is no annual volume which offers a greater interest to philosophically inclined students of the sciences of life and mind.

The eugenic problem is approached from two sides, practical and theoretical. In his paper on A Practical Eugenic Suggestion, Mr. McDougall advocates the remuneration of the services of every person belonging to a specially selected class (*e. g.*, the class of civil servants) not, as at present, according to some rigid scale, but according to a sliding scale such that his income shall be larger in proportion to the number of his living offspring. From the theoretical side, Dr. Reid endeavors, in The Biological Foundations of Sociology, to throw light on the questions of human heredity and variability; and Dr. Tayler, in The Study of Individuals (Individuology) and Their Natural Groupings (Sociology), advances the thesis that the fundamental social formations are determined by the native characteristics of individuals.

A paper of great general importance to students of sociology is Professor Thomson's essay on The Sociological Appeal to Biology. The writer discusses various borderland problems involved in the relation of the two sciences, and thus places in their right connection a number of previously isolated studies. Professor Geddes's third paper on Civics (A Suggested Plan for a Civic Museum or Civic Exhibition and its Associated Studies) continues his attempt to afford insight into the life processes of the city.

A division of sociology not hitherto represented in the present series of publications, that of religion, is opened by Mr. Crawley's paper on The Origin and Function of Religion. Religion is defined as a psychic tone, temper, or diathesis; its sphere is the consecration of such elemental concerns as birth, adolescence, marriage, sickness and death; its objective, in one word, is life; and its first and last biological result is to raise human nature to a higher power.

Sociology is applied to the interpretation of concrete social phenomena in three papers: those of Professor Wenley on Sociology as an Academic Subject, by Mr. Beveridge on the Problem of the Unemployed, and by Mr. de Wesselitsky on the Russian Revolution.

Finally, two methodological papers (Mrs. Webb, on Methods of Investigation, and Mr. Wells, on The So-called Science of Sociology) deal with matters of practical procedure in sociological investigation.
M. W. WISEMAN.

American Philosophy. The Early Schools, by I. WOODBRIDGE RILEY. Dodd, Mead & Co., New York, 1907. pp. 595.

This work attempts to give a thorough and consecutive account of philosophy as developed in the United States from the landing of the Pilgrims to the advent of Emerson. It is based upon individual investigations, many rare works and unpublished manuscripts, and presents an account of the most important speculative movements, as they were transferred from Europe and developed during two centuries, thus slowly preparing the way for Emerson. It is the result of a three years' tenure of the Johnson Scholarship at Johns Hopkins. The chief sections are Puritanism, Idealism, Deism, Materialism and Realism. The present volume does not come down much beyond 1850.

Die Kultur der Gegenwart, ihre Entwicklung und ihre Ziele, herausgegeben von PAUL HINNEBERG. *Teil I, Abteilung VI, Systematische Philosophie.* Tuebner, Berlin and Leipzig, 1907. pp. viii, 432.

This volume is one of a series intended to present in encyclopedic fashion the whole circuit of modern intellectual life both theoretical and practical. Of the total work six volumes have appeared besides the present one upon Systematic Philosophy, for which the editor has been able to call to his assistance the ablest of German scholars. A work with a table of contents like the following is its own strongest commendation: DILTHEY, The Nature of Philosophy; RIEHL, Logic and Epistemology; WUNDT, Metaphysics; OSTWALD, Philosophy of Nature; EBBINGHAUS, Psychology; EUCKEN, Philosophy of History; PAULSEN, Ethics; MÜNCH, Pedagogy; LIPPS, Æsthetics; PAULSEN, The Future of Philosophy.
E. C. S.

Sammelbericht über die neuere Forschung in der Gedächtnis- und Assoziationspsychologie aus den Jahren, 1903-4, by HENRY J. WATT. Off-print from the Arch. f. d. ges. Psychol., 1906, 7 (Lit.), 1-48.

The author passes under critical review the more important papers in a bibliography of some sixty titles upon memory and the associative processes published during the years 1903-1904. The papers are treated in thirteen sections upon the following topics: General questions, General effects of practice, Methods and Instruments, Economical learning, Retention (perseveration), Influence of the feelings on memory, Recognition, Processes of thought, Association, Mediate association, Reaction times, Visual ideas, Characteristic mental types. The work appears to have been carefully and judiciously done and the review can be recommended as an excellent guide to the literature of the period which it covers.
E. C. S.

Leitfaden der Psychologie, von THEODOR LIPPS. Zweite, völlig umgearbeitete Auflage. Leipzig, Wilhelm Engelman, 1906. pp. 360.

Vom Fühlen, Wollen und Denken, Versuch einer Theorie des Willens, von THEODOR LIPPS. Zweite, völlig umgearbeitete Auflage. Leipzig, Johann Ambrosius Barth, 1907. pp. 275.

Both of these second editions fully justify their designation as *völlig umgearbeitete*. The first has not been greatly increased in bulk, but gives evidence at least in the table of contents of a thorough working

over of almost every section. The second is only nominally a reproduction of the earlier work of the same name, the author himself speaking of it as practically a new book with a special purpose indicated by its subtitle; "an attempt at a theory of the will." The number of pages have been increased by nearly two-fifths.

Both works are characterized by Lipps's singularly lucid style and by their lack of explicit reference to the work and views of others. History and controversy are wholly omitted and the infrequent footnotes refer almost without exception not to the work of others, but to sections in other works of the author where the matters in hand are more fully dealt with. Very much may be said in favor of such an unencumbered presentation of the subject matter, especially in works written for the general reader, though in the case of psychology it is apt to give rather too simple and unified an impression of the *status praesens* of the science. The omission of the brief introductory note, which in the first edition of the *Leitfaden* explained this feature of the work, makes the author's attitude especially liable to misconception by those who see the second edition only. E. C. S.

A Primer of Psychology and Mental Disease: for use in Training-Schools for Attendants and Nurses, and in Medical Classes, and as a ready reference for the Practitioner. By C. B. BURR. F. A. Davis Co., Philadelphia, 1906. pp. viii, 183. Price $1.25.

This little work falls into four parts. Pt. i (Psychology) gives a 40-page sketch of a faculty psychology, under the heads of thinking, feeling and volition, which might easily be improved as psychology, though it may do service as introducing the class of readers to which the book appeals to the more special study of insanity. Pt. ii (Insanity: 90 pp.) is a competent essay, from the medical point of view, on the definition, causes and forms of insanity. Pts. iii and iv outline briefly (15 and 25 pp., respectively) the method of treatment of cases from the medical and the nursing standpoint: they are sensibly and judiciously written.

The fact that the book, published in 1898, is now in its third edition is sufficient evidence of its practical utility. It would be well if the author could see his way, in the event of a future edition, to co-operation with some psychologist of standing for a re-writing of Pt. i.

P. E. WINTER.

Anatomy of the Brain and Spinal Cord with special reference to mechanism and Function. For students and practitioners. By HARRIS E. SANTER. Fourth ed. Revised and enlarged. P. Blakiston's Sons & Company, Philadelphia, 1907. pp. 453.

The author attempts to set forth the present status of the anatomy of the human brain and spinal cord, gleaning his facts from many sources. Since it is designed as a text-book, the subject matter is presented in an order convenient to the dissector and the descriptions presented from gross structures to the constituent neurons in each region. Embryology is used only where it assists in the comprehension of adult forms—this in the text, but a special chapter is also given to embryology. The special end in view is the localization of functional centres and the traits of their afferent, associative and efferent connections. Much stress is laid on origin, termination, course and function of conduction paths, and the more important and better known of these are summed up in the final chapter. Everywhere function is correlated with structure, and the function of each neuron is given in connection with its anatomical description. This, we should say, is the unique and most valuable feature of the book. The B. N. A. nomenclature is used almost without exception, the English equivalents of the Latin

terms being very largely employed. The student is expected to discuss as he goes along, and each should receive a section corresponding to those which are made units of treatment in this book.

Compensatory Motions and the Semi-circular Canals, by BENJAMIN C. GRUENBERG. Reprinted from the Journal of Experimental Zoölogy. Vol. IV, No. 3, Baltimore, Sept., 1907. pp. 447-467.

These experiments show apparent contradiction between the various responses of the frog to rotation on the turn-table and the theory of mechanical stimulation as the origin of these responses. A re-examination of the compensatory movements under these conditions shows the presence of a mechanical factor, the "spin," the significance of which in this connection seems not to have been considered before. From all the data the writer concludes that the compensatory movements of the frog's head caused by rotation arise in response to two distinct sets of stimuli: the visual, which is relatively feebler and slower, and the dynamic factor located in the internal ear, the latter involving rotation.

Cradle Tales of Hinduism. By the SISTER NIVEDITA (M. E. NOBLE.) Longmans, Green & Co., London, 1907. pp. xv, 343.

The stories here told form "a collection of genuine Indian nursery-tales," taken mainly from the Puranas, works which correspond to our apocryphal Gospels; from the Mahabharata, the Indian national saga; and from the Ramayana, the epic of Indian womanhood. The tales are entitled the Cycle of Snake Tales; The Story of Siva, the Great God; The Cycle of Indian Wifehood; The Cycle of the Ramayana; The Cycle of Krishna; Tales of the Devotees; A Cycle of Great Kings; and A Cycle from the Mahabharata. The reviewer is not competent to pass a technical judgment upon the authenticity of the stories themselves, or upon the historical questions raised by the author in her preface. He has, however, read the book with great interest, and can testify to the sustained excellence of the presentation and the intrinsic value of the tales. H. W. HOTCHKISS.

Hygiene of Nerves and Mind in Health and Disease, by AUGUST FOREL. Authorized translation from the second Berlin edition by Herbert Austin Aikins. G. P. Putnam's Sons, New York, 1907. pp. 343.

This interesting book well merited translation and that of Professor Aikins is lucid and conscientious. It is divided into three parts; the first treating of mind, brain and nerves in their normal condition. This is an admirable compend for what is now known, is sufficiently illustrated for the author's purpose, and constitutes a little more than one-third of the book. The second part is on the pathology of the nervous life, containing the general idea of pathology, a synopsis of mental diseases and abnormalities and their causes. The third part discusses the hygiene of mental life and of the nervous system. Professor Forel is never dull and his discussions abound with concrete cases and applications which give an unusual liveliness to his pages.

BOOK NOTES.

Concerning the Intelligence of Raccoons, by L. W. COLE. Reprinted from the Journal of Comparative Neurology and Psychology, May, 1907. Vol. XVII, No. 3. pp. 211-261.

The author has tried to determine what type of association the raccoon is able to form, the complexity and the permanency of its associations, and to ascertain whether mental images and the tendency to imitate are present in this animal. The original plan was to make observations upon the senses, instincts and habits of the raccoon in general, and to compare these observations with those made upon other mammals under similar experimental conditions. These observations, however, are omitted from this article. All were based upon six young raccoons—four males and two females. They learned to release fastenings, to discriminate form and color (when associated with brightness), to imitate, showed a good deal of power to learn from being put through an act; and the reactions to the present and mental images were marked. The coon, the author thinks, stands midway in the rapidity of the associations it forms between the monkey and the cat, being nearer the former in their complexity. Only after practice are motor associations permanent, and two types of learning and forgetting are clearly distinguished. The coon discriminates form, size, tone, and color when combined with intensity. There is no evidence that the coon imitates its fellows. Many of Mr. Cole's conclusions are confirmed by similar observations by Mr. H. B. Davis, published in the last number of the *American Journal*.

The Dancing Mouse, a study in animal behavior. By ROBERT M. YERKES. The Animal Behavior Series, Vol. I. The Macmillan Company, New York, 1907. pp. 290.

The writer treats the origin and history, feeding, breeding and development of the young and then turns to the special discussion of the behavior of the dancing mouse, equilibrium, dizziness, structural peculiarities, sense of hearing, sight, color, educability, etc. He also conducts the young mice to the labyrinth, tests their discrimination and the efficiency of various training methods, studies duration of habit, memory and relearning, individual, age and sex differences, inheritance of forms of behavior. It is an interesting and painstaking study and all those who care for this kind of work will await with interest later volumes of this series.

The Measurement of Variable Quantities, by FRANZ BOAS. Archives of Philosophy, Psychology and Scientific Methods. No. 5, June, 1906. New York, the Science Press. pp. 52.

This short monograph gives the substance of a course of lectures given by Prof. Boas for a number of years to students of anthropology, biology, and psychology at Columbia. Because of the small mathematical attainments of such students as a class, the treatment for the most part steers clear of the calculus. The reviewer with others is grateful to Dr. Boas for thus making his lectures generally accessible, but conscience compels him to say that since Dr. Boas has not been able to eliminate the natural difficulties and complexities of the sub-

ject along with the calculus, the non-mathematical student will not find the monograph easy reading. E. C. S.

Poetry and the Individual, an Analysis of the Imaginative Life in Relation to the Creative Spirit in Man and Nature, by HARTLEY BURR ALEXANDER. G. P. Putnam's Sons. New York and London, 1906. pp. x: 240.

The general character of this work can perhaps be most briefly indicated by saying that it is a modern work on the æsthetics of poetry conceived and executed in the spirit of Plato, and possessing much the same sort of excellencies and defects that characterize that master. The author says in his preface that the reason modern idealism is deficient in vital effectiveness is that its representatives have taken up the "cultivation of intellectual subtleties to the neglect of the practical idealism which their thought should really contain." "The philosophical need, then, is *humanisation* of philosophical interests. . . . . The book here offered aims by a sort of natural criticism to lay bare some of the instinctive modes of human thought and to assist the major philosophical task." The work is literary in manner—at times over much so—an essay always, rather than a scientific treatise,—evidently the work of a man of insight who has dealt at first hand with that of which he writes. E. C. S.

Twenty-fifth Annual Report of the Bureau of American Ethnology to the Secretary of the Smithsonian Institution 1903-4. Government Printing Office, Washington, 1907. pp. 296, and 129 plates.

This is a very timely study of the aborigines of Porto Rico and neighboring islands by J. N. Fewkes, who also appends a paper on certain antiquities of Mexico. Both are copiously illustrated and, indeed, about half the volume is made up of full-page cuts besides those inserted in the text.

The Physician's Visiting List for 1908, published by P. Blakiston's Son and Co., Philadelphia. Price $1.00.

A conveniently arranged physician's diary, address book and cash account, containing also other data likely to be useful to a forgetful man of medicine. E. C. S.

The Lords of Ghostland. A history of the idol. By EDGAR SALTUS. Mitchel Kennerley, New York, 1907. pp. 215.

This work consists of chapters on Brahma, Ormuzd, Armon-Râ, Bel-Marduk, Jehovah, Zeus, Jupiter, Ne Plus Ultra.

Normal Activity of the White Rat at Different Ages, by JAMES ROLLIN SLONAKER. Reprinted from the Journal of Comparative Neurology and Psychology. July, 1907, Vol. XVII, No. 4. pp. 342-359.

Menschen- und Tierseele, von E. WASMANN. J. P. Bachem, Köln, 1907. pp. 16.

The New Mysticism. Six lectures given in Kensington, and at Cobham, Surrey, November, 1906, by ADELA CURTIS. Curtis & Davison, London, 1906. pp. 196.

Philosophical Problems in the Light of Vital Organization, by EDMUND MONTGOMERY. G. P. Putnam's Sons, New York and London, 1907. pp. 462.

Shake-Speare England's Ulysses, by LATHAM DAVIS. G. E. Stechert & Co., New York.